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PAPERS

CONNECTED WITH THE

CONSTRUCTION OF THE MADRAS HARBOUR.

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PAPERS

CONNECTED WITH

THE CONSTRUCTION OF THE MADRAS HARBOUR.

Letter from Madras Chamber of Commerce, to the Secretary to the Government of Madras in Marine Department, on the necessity of providing some protection for ships lying at Madras,—dated 31st July 1868.

The Chamber of Commerce has had under consideration a proposal to form a break-water about 1½ miles long, in a depth of 6 or 7 fathoms of water, parallel to the shore of Madras, the effect of which would be to make a safe and commodious anchorage for ships, and to render the shipping operations of this port independent of the uncertain aid of surf-boats.

2. I am now instructed by the Chamber to bring this subject to the prominent notice of Government, and to urge the importance of some such work, not only to the special interests of the body which I represent, but to the general public, and to all who have any stake in the prosperity of Madras.

3. It does not come within the province of the Chamber to discuss the break-water from an engineering point of view, as Government has easy means within reach of ascertaining the practicability of the work, and of obtaining an estimate of its cost sufficiently close to decide whether the growing necessities of the Madras trade justify the expenditure. It may suffice to express the strong opinion of the Chamber, that if Madras is to do justice to the commerce which her growing net-work of roads and railways is laying open to her, it is essential that her surf be, so far as possible, done away with. That this would be the effect of the formation of a break-water is what the Chamber is glad to believe.

4. But there is another aspect in which the formation of a break-water ought to be regarded, and that is, the absence at present of anything at all deserving the name of a harbour of refuge on any part of the Coromandel Coast. Considering the extent of this coast, and the frequent storms that sweep the Bay of Bengal, the Chamber cannot but think Government will concur in the opinion that, even if no returns were to be looked for on the capital sunk, money would be well and wisely expended that provided a harbour of refuge. That Madras as the capital of the Presidency, and the most important town on the coast, is the place where such a harbour should be formed, the Chamber does not entertain a doubt, and it is only here that a break-water would have a chance of combining financial success with incalculable benefit to the fleets that frequent these seas.

5. The Chamber is aware that the "financial success" of the break-water would depend entirely on its cost, and when that has been ascertained, it will be easy to calculate whether the shipping of Madras can afford port dues sufficiently high to give a fair interest on the capital invested. From all that the Chamber can learn, it does not seem a too sanguine estimate to affirm that one rupee per ton, levied on the tonnage at present frequenting Madras, will yield a handsome return on the most liberal estimate of the cost of the break-water. The Chamber is quite sure that no ship-owner would object to the above charge per ton, when he considered the difference of the security afforded his property by our present open roadstead, and the safe anchorage a break-water would give.

The Chamber further believes that a greater number of ships would be attracted to Madras than at present, and that we would have more produce to fill them, no onecan doubt who sees how the most remote districts are being tapped and brought into easy communication with the sea. The Chamber, therefore, thinks that, even on the score of being a paying investment, the break-water is a work that ought to be undertaken.

6. The Chamber would then respectfully beg Government to give this project their prompt and most favourable consideration. That a break-water at Madras is a public work of the first utility, is admitted on all hands, and it is therefore with the utmost confidence that the Chamber appeals to Government for its aid in carrying out the project. The expenditure in

making a break-water would be a gradual one, so much per annum for a certain number of years. The Chamber is of opinion that a work of such magnitude and utility would be best accomplished by Government and its servants, and the funds could be raised without difficulty by the issue of Debenture Bonds, similar to those issued for previous Public Works Loans. It would not be long before the progress of the work would justify an increase to the present port-dues, and so some return on the expenditure would begin to come in to Government. In the event of Government not entertaining favourably the idea of undertaking the work themselves, the Chamber would suggest that a guarantee of 5 per cent. on the cost of the break-water be promised to any Company that undertakes its formation. In either of these ways there would be no difficulty in obtaining the money, but the Chamber is decidedly of opinion that the first would be the best, the making of a break-water here being essentially an " Imperial work."

7. The Chamber will look forward with anxiety to your reply to this letter, and I am in great hope that the project now laid before Government will meet with the hearty support it deserves, and that the opportunity of initiating so great a work will not be let slip.

Minute by His Excellency Lord Napier on the above,—dated 23rd August 1868.

The Chamber of Commerce has submitted to Government an emphatic representation in favour of a project often suggested, abandoned, and revived—the construction of a break-water for the protection of the Madras roads. The Government have entertained the proposal, and have engaged to prepare a plan and estimate for the contemplated undertaking. The subject has been referred to the Department of Public Works. No one can dispute the importance and utility of the design, and there are many considerations, having reference either to the permanent rights and interests of the Presidency, or to the accidents and features of the present time, which justify Government in affording it their prompt attention and earnest advocacy.

2. The primary object of a break-water is to shelter the ordinary operations of import and export commerce. The recent accident to the pier, an accident to which it must always be exposed, has presented a practical proof of the insecurity attached to the imperfect agencies for shipping and landing goods with which the port is at present furnished. We want calm water, safe anchorage, secure landing-places; facilities for docking and repairing ships; facilities for embarking and disembarking troops, stores, and munitions of war; uninterrupted communications, and exoneration from the exclusive service of a skilled and privileged class of boatmen.

3. The roads of Madras, defended by a break-water, would not only form a convenient local commercial port, they would also open a port of refuge for all vessels navigating on this coast of India, both against the sustained violence of the north-east monsoon, and the unforeseen attacks of the rotatory storms, which from time to time traverse these seas with destructive power. The Chamber of Commerce has justly remarked that there is nothing deserving the name of a harbour of refuge on the Coromandel Coast. There is, in point of fact, no place of real safety between Trincomalee and the Hooghly. I have no means of compiling the calamities which have occurred along this vast extent of monotonous shore. It is commonly asserted that the value of the merchandise and vessels wrecked within the memory of old residents, on 5 miles of beach between Royapuram and St. Thomé, amounts to a sum more than sufficient to build a defensive bulwark which would make a single wreck impossible. I do not doubt it. This particular point of the coast has of late been wonderfully spared, but the reiterated examples of Masulipatam and Calcutta are calculated to fix our anxieties on a peril which is always impending.

4. The danger of a defenceless roadstead is, however, not only a weather danger, it is also a war danger. I would ask the Government to paint to themselves the roads of Madras at the height of the export season without a break-water, but with a sea-breeze, and a single French or American cruizer in the offing. The same picture would do on a smaller scale for the Provincial ports. The same scene of terror, confusion, dispersion, and disaster would everywhere occur. But the construction of an armed break-water would be a rampart to the ships in the roads, and would afford a ready refuge for all vessels scattered along the coast in the case of sudden emergency.

5. A defence so useful to the shipping would not be less useful to the shore. It is certain that Madras is becoming more valuable and more vulnerable every day. The old works towards the sea are rather a source of risk to the city than of safety. They would attract and justify an attack. They would never repel an enemy. But, while the place has become more obnoxious to insult and aggression in consequence of the developments of maritime offence,

the Government have, for various good reasons, drawn out all their most costly establishments in naked array upon the shore. The Railway Terminus, the Sailors' Home, the Commissariat Offices and Depôts, the Custom House, the Stamp Office, the Offices of Government in the Civil and Military Departments at the Fort, the Government House, the Senate House, the Revenue Board, the Engineering College, the Public Works Depôt, and the Presidency College, form an extended front of public property ranked conspicuous and inviting in the face of a hostile fleet with the most slender provision for protection or resistance. I need only allude to the crowded and perishable Native quarters, to the Hospitals and Jails, to the Offices and Ware-houses of the traders. It is obvious that all the elements of weakness, suffering, sacrifice, and disgrace are accumulated in this defenceless capital in a degree scarcely exemplified elsewhere, even on British territory. It is equally certain that a fortified break-water would afford a great measure of security to life and property on shore, and that no other description of works would give any security whatever.

6. To these considerations we must add another reflection of the most serious character. Without a break-water not only the trade of Madras must ever be insecure and intermittent and its establishments, inhabitant, and property must lie at the mercy of a maritime adversary, but without a break-water the trade of Madras may cease to exist altogether. The development of the Railway system, which will shortly bring the central regions of India into rapid and easy communication with either coast, places the existence of the old commercial emporiums in question. It is certain that the direction of traffic will not be determined by the cost of transport to the sea-board only; it will be governed by the convenience, safety, accessibility, and charges of the maritime terminus, and by the relation in which that terminus stands to the European markets. The natural advantages possessed in these respects by Bombay will soon be reinforced by a most powerful artificial auxiliary, the Suez Canal. By such a combination it is scarcely too much to say that the whole trade of India might be drawn into a single focus, unless the ports on the eastern sea-board avail themselves in time of all the expedients by which science and labour correct the defects and tendencies of nature, and thus secure for each presidency an equitable share in the benefits of commerce.

7. The expediency of constructing a break-water at Madras needs no further demonstration at my hands. The arguments in favour of the undertaking are patent to all in this Presidency, and were never so generally admitted and deeply felt as at the present conjuncture. The enterprise is, however, one of great magnitude and cost. Many impediments and delays must be encountered and surmounted before the first cargo of stone can be deposited in the sea. The prudent incredulity of superior authorities must be patiently and slowly vanquished. The Supreme Government and the Government at Home will require not only a demonstration of the necessity, the practicability, and the profitableness of the project, but that demonstration must be urged by all the influences which may be properly enlisted on behalf of schemes of public utility. The consent of scientific judgment, official sanction, and public support will at least be indispensable, and to these powers it may perhaps be necessary to add the co-operation of private capital. It appears to me desirable that the design should not emanate directly and simply from the Department of Public Works. It is one of a very complicated character, in which many considerations of a maritime, military, commercial, and financial nature are involved, as well as technical questions of engineering. I think that the preparation of the plan and estimates may properly be entrusted to a Commission embracing representatives of the various interests concerned. If my colleagues assent to this proposal, they may naturally expect to see me add the suggestion that the Secretary for the Public Works Department should be placed at the head of this deliberation. Colonel Orr, however, considers that he can be of greater use as a source of information and counsel outside of the Commission, and he is anxious to place all his ability and all his plans at their disposal. I beg, therefore, to suggest that a Commission be embodied by Government, to frame plans and estimates for a fortified break-water at Madras, composed of the following persons:—Colonel Anderson, Colonel Carpendale, Major Shaw-Stewart, Mr. Elphinstone Dalrymple, Mr. Elwin, if he will obligingly grant his services, and a gentleman who may be selected by the Chamber of Commerce. The enquiries and the report of the Commission need not be limited to the preparation of plans. They should be invited to deal with the subject in all its bearings, including the agency by which the execution of the work might most properly be undertaken, and the provisions by which it might be rendered profitable as a financial investment. It is possible that, with the aid of a Government guarantee, the Madras Railway Company might be disposed to associate itself to a project with which the interests of the railway are so closely identified, I do not, however, desire to discredit the opinion enunciated by the Chamber of Commerce that the break-water should be an Imperial work. The immense expenditure sanctioned by the Supreme Government for the improvement and defence of the harbour

of Bombay, and the liabilities directly or indirectly incurred for the encouragement of Port Canning, give the Government of Madras a right to appeal to the Government of India, and an assurance that their appeal, if well founded and supported, will not be made in vain.

Order of the Government of Madras, nominating certain officers to form themselves into a Committee for the preparation of plans and estimates for the proposed break-water,—No 2773, dated 28th August 1868.

On fuller deliberation, the Government are of opinion that the subject of constructing a break-water at Madras involves the consideration of so many questions of a maritime, military, commercial. and financial nature, as well as of a technical and engineering character, as to render it expedient that its investigation should be entrusted to a Commission composed of representatives of the various interests concerned. His Excellency the Governor in Council accordingly resolves to nominate the Officers named in the margin to form themselves into a Committee for the preparation of the plans and estimates. Mr. Elwin has obligingly intimated his willingness to grant his services, and the Chamber of Commerce will be requested to nominate to the Committee a gentleman to represent that body.

Colonel J. Carpendale, R.E.
Colonel J. C. Anderson, R.E.
Major J. H. M. Shaw-Stewart, R.E.
Mr. H. D. E. Dalrymple.
Mr. R. B. Elwin.

2. The enquiries and the report of the Commission should not be limited to the preparation of plans. They will be requested to deal with the subject in all its bearings, including the agency by which the execution of the work may most properly be undertaken, and the provisions by which it may be made profitable as a financial investment.

Report of the above Committee,—dated 16th January 1869.

We have the honour to report on the subject of a break-water, which was referred to us in Order of Government No. 2773, of the 28th August 1868. In prosecuting our enquiry we have been fully impressed with a sense of the responsibility attaching to our deliberations, and, while availing ourselves of all information on record, we have also freely sought the opinions of a variety of gentlemen, who were qualified, by profession and experience, to aid us in forming a correct judgment on the several heads into which the subject naturally divides itself and the evidence of these gentlemen will be found *in extenso* in Appendix A.

2. *Blackwood's Harbour.*—Any report on the improvement of the Port of Madras by the construction of a break-water, would be incomplete without reference to the alternative project of improving "Blackwood's Harbour," at Armogum Shoal, 45 miles north of Madras, which always has advocates when the subject of a break-water or a harbour at Madras is broached; but having recent evidence, in the case of "Port Canning," of how futile it is to expect to divert the trade of an old-established city to a new port, however great its natural advantage, we did not consider it necessary to extend our enquiry to the site in question particularly as our instructions limited us to the improvement of the Port of Madras. We may, however, incidentally mention that Blackwood's Harbour is formed by a shoal very similar, as regards its action in producing still water in-shore, to a detached break-water parallel to the beach.

3. From the tenor of our instructions it is to be inferred that the Government are fully convinced of the necessity of some improvement to the port being devised, and that a break-water of some kind would be the most suitable means of attaining the object, but we felt that our report would be more complete, and more satisfactory to the authorities at a distance, before whom the project may ultimately come for decision, if it embraced the question of a close harbour; and we trust we shall not be considered to have travelled beyond our province, if; for the same reasons, we briefly notice the present condition of the port, and the altered circumstances which the construction of a break-water is expected to produce.

4. *Present condition of the Port of Madras.*—The Port of Madras at the present time, so far as the facilities for trade are concerned, differs very little from what it was nearly 250 years ago, when, as a small fishing village, it first attracted attention. It remains an open roadstead, destitute of any natural shelter, and still unprovided with any artificial substitute, and its surf still offers an insurmountable difficulty to the passage of boats of every kind, except the primitive Masoolah boats. But though manned by thirteen trained men, a Masoolah boat carries only one and a half tons as an ordinary load in the finest weather, and often less than half a ton in heavy weather. The very skill of the boatmen is one of the difficulties of the port, for their numbers being limited, they are able to set regulations at defiance, and to charge pretty much what they like,—twice, four, and six times the legal hire being a common rate

and ten times by no means uncommon; well knowing that the course which would elsewhere be followed of importing additional men from other localities, would be inoperative at Madras, for in consequence of caste prejudices, and the disinclination of the Natives to adopt customs or to follow trades which have not been followed by their fathers before them, the ordinary laws of political economy cannot be applied in their integrity in this country, and it does not follow because there is a greater demand than supply of Masoolah boatmen, and a very handsome profit to be reaped by those who might qualify for the occupation, that outsiders will qualify for it and come forward to break the monopoly.

5. *Objections to the Port of Madras.*—The great objections, then, to the Port of Madras are—

1st.—That it is an open roadstead, destitute of shelter, which renders it necessary, on the approach of a gale, for ships to put to sea for safety; or if out of trim or ballast, and unable to put to sea, to incur the imminent risk of dragging their anchors, or of parting from them and going ashore, complete wrecks.

2nd.—That owing to the communication between the shipping and the shore being for the most part by Masoolah boats only, carrying one and a half tons at a time, the delay in loading and unloading is so great as to deter many ships, to which a preference would be given, from coming to the port at all.

3rd.—That the actual cost of landing and shipping cargo, even at legal rates, is needlessly great; while the much higher rates which the mercantile community pay on demand, rather than incur the inconvenience and odium of prosecuting the boatmen, enhances the cost so much as to become a formidable addition to the charges of a Port otherwise regarded as a cheap one.

4th.—That, notwithstanding the skill of the boatmen, the damage to goods from spray and from shipping seas in crossing the surf, is a very serious consideration.

6. *Screw Pile Pier.*—It is true that the Screw Pile Pier was constructed with the object of overcoming these difficulties, but just when there was a good prospect of its turning out a success, when people had become accustomed to frequent it, and when suitable cargo boats had been brought into use, it was struck by a French barque, which had drifted from its anchor, in by no means bad weather. The result was the total wreck of the vessel, and a breach in the body of the structure, 250 feet in length, which it will take more than twelve months to repair.

7. *Advantages of a break-water.*—The object of a break-water is to create comparatively smooth water between it and the shore, where vessels of all kinds can anchor, and, it is believed, shall be able to ride out a gale in safety either at their own anchors or at fixed moorings. It will furnish a harbour of refuge also to ships within a considerable distance of Madras, both from the violence of the gales so prevalent at certain seasons in the Bay of Bengal, as well as from the armed vessels of an enemy; but the principal advantage it will afford at ordinary times, will be in the effect it will have in completely subduing the surf, and thus of allowing of cargo being loaded or unloaded by boats of ordinary construction and of large dimensions, with the result of a great reduction in the time of a ship's detention in the roads, and an equally important saving to the mercantile community, by a lowering of the scale of boat-hire and the avoidance of damage to goods.

8. *Colonel Orr's design.*—On our first meeting, Colonel C. A. Orr, R.E., placed before us a memorandum with illustrative drawings of the break-water proposed by Mr. deClosets and himself, and which we shall describe hereafter. We have also received for consideration several other designs by professional Engineers, which we shall notice separately.

Appendix B.

9. *Close Harbour.*—We fully considered, at an early stage of our proceedings, the question of forming a closed harbour in preference to a break-water parallel to the shore, and we are of opinion that a harbour formed by stone dykes running out at any angle with the shore, and for any length, would be ineffectual, and that the inevitable result of such a construction in the Madras roads would be the eventual extension of the beach, and the complete closure of the mouth of the harbour, followed in course of time by the shoaling up of the harbour itself.

10. *Design by R. F. Chisholm, Esq., C.E.*—We gave our best consideration to a scheme laid before us by Mr. R. F. Chisholm, C.E., for the construction of a break-water, formed of a combination of stone and timber framework, on the principle which has been adopted for a break-water at Blythe, on the coast of Northumberland, and while recognising the ingenuity of this plan, we are of opinion that very great difficulty would be experienced in raising a structure of the kind described, in the heavy sea which frequently prevails in the Madras roads; that it would be very

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liable to be destroyed in the process of construction by a storm; and that, even if it were carried to completion, no dependence could be placed in the durability of any framework of timber, since it has been proved that this material, whether creosoted or not, cannot resist the ravages of the *Teredo navalis* in the Madras roads.

11. *Break-water of screw piles and screens.*—We are also of opinion that a break-water in the form of an open structure of screw pile work, furnished with screens for breaking the force of the waves, would be unsuitable. Not only would such a work be excessively expensive, owing to the great depth of water to be dealt with, and the depth of soil which would have to be penetrated in order to insure its stability, but it would be liable to injury from ships running foul of it.

12. *Design by Mr. J. P. Doyle, C.E.*—We read with great interest Mr. Doyle's able and very carefully considered report; but while we acknowledge that the design has great merit, we are constrained to record that, in our opinion, it has the fatal objection of the enormous expense which would have to be incurred in screwing piles in so great a depth of water as 42 feet, and in the payment of divers and other skilled labourers. We also consider that the proposed extension of the pier to meet the break-water, and the gaps in the solid construction, whould be a great source of weakness, and further, that it is extremely doubtful, even if the work were completed as proposed, whether it would have sufficient strength to withstand heavy blows of the sea in a bad weather, while it would also be liable to sustain serious injury from vessels falling foul of it.

Appendix D.

13. *Design by Mr. W. Fraser, C.E.*—Mr. Fraser advocates the formation of a closed harbour, and has furnished us with a memorandum explanatory of his reasons for preferring that mode of construction to a break-water. He is of opinion that the quantity of sand and silt in motion along the coast at Madras is very small, and that it receives little or no accession from any source; also, that groynes thrown out from the beach, at points to the north and south of Madras, would intercept the greater part of the sand, and would prevent the small quantity which would continue in motion from occasioning any serious injury to a harbour formed by solid piers run from the shore at Madras, into six or seven fathoms water.

Appendix E.

We cannot agree with Mr. Fraser either that the quantity of sand which is carried along the shore by the littoral currents is of so limited an amount as to render it capable of being controlled by artificial works, or that the effect of a series of groynes would in any way differ from that of the small groynes which have already been thrown out from the beach at Madras which has practically resulted in the extension of the beach to near the ends of the groynes The actual quantity of sand moved along the shore is certainly unknown, but if the construction of groynes leads to the formation of a new sea-beach in advance of the original one, and precisely similar to it, the inference is, that either the sand which has been heaped up was derived from material brought to the spot by littoral currents, or that, if it were thrown up by the surf, the quantity thus obtained from the bed of the sea was replaced by an equal quantity brought from a distance. We consider there is strong reason to conclude that if a beach is extended a hundred yards by means of groynes, it might be extended a hundred yards further by continuing the process, and in each case a new line of beach being formed precisely similar to the original beach, there would appear to be nothing to prevent the shore being extended to any amount that might be desired.

On these grounds we consider Mr. Fraser's project as altogether unsuited for the Madras roads.

14. *Design by Mr. Rymer-Jones.*—Mr. Jones' project differs from Mr. Fraser's in providing a combination of open screw pile work and solid masonry piers instead of solid piers throughout; but although the space thus left near the shore ends of the work would allow of the littoral currents passing close along the shore, we do not consider this would suffice to prevent a shoaling up of the harbour where it would be screened from the action of the current. The water would be still there, or what motion there would be, would take the form of eddies, which would draw in the sand or silt in suspension along the line of the current, and deposit it in the bottom of the harbour. Moreover, as the solid work of the piers would expose a large surface of resistance to the currents running parallel to the shore, the latter must be deflected either into two distinct streams, one running along the beach, and the other along the outer ends of the piers, or into one outside the pier ends only. Now, both from the form of the proposed piers, and from the fact that the resistance to motion through the screw pile work at the shore ends of the piers would be greater than if there was no work standing in the way of the current, it is to be concluded that the tendency to motion towards the outer end of the piers would preponderate

Appendix F.

from the very first; that this tendency would go on increasing the longer the work was in operation, and that, as every portion of motion lost from the line of the shore would lead to a deposit of sedimentary matter, the final shoaling up of the bed of the sea to the outer end of the proposed harbour, followed by the shoaling of the harbour itself, would be the inevitable result.

Mr. Jones proposes to construct the piers partly of coursed masonry. The principle of his project is unaffected by the nature of the materials used for the piers, but, as we have already mentioned, we consider that a style of construction which would necessitate the employment of a vast amount of skilled labour is to be strongly deprecated.

15. *Design by Mr. George Wells, C.E., and Captain Heathorn.*—For the reasons stated at length in the preceding paragraph, we cannot recommend for adoption the project brought forward by Mr. George Wells, C.E., and Captain Heathorn.

Appendix G.

16. *Design by Mr. Samuel Perkes, C.E.*—The objections which we have urged against the adoption of a closed harbour in our remarks on Mr. Fraser's project, are equally applicable to that submitted by Mr. Perkes, and being strongly of opinion that no closed harbour at Madras, however ingeniously arranged, could be protected from shoaling up, we consider it unnecessary to enter upon a detailed examination of Mr. Perkes' design. We may, however, remark that if there is any truth in the tradition that the shore at Madras was formerly 2 or 3 miles in advance of the present line, it must follow that the sea which has shown its power to abrade and carry away so vast an amount of material, must have equally the power of re-conveying a like amount of material, and of depositing it in the former position.

Appendix H.

17. Two plans of boat harbours have been submitted for our consideration, one by Captain Taylor, R.N.R., Commanding the Ship "Renown," and the other by Mr. J. Bell, an Assistant Engineer in the Public Works Department.

18. Captain Taylor proposes to extend the present pier head to a length of 500 feet, to protect it from injury from ships by large booms moored at some distance from it, and to break the swell of the sea by means of a coir net hanging outside the pier head and weighted at the bottom. This, he considers, would sufficiently subdue the swell to allow of boats plying without difficulty to and from the beach in moderate weather. He further proposes to excavate a basin on each side of the pier end, which would form a boat harbour, the mouths to which would be nearly in the line of the existing beach. The central part of the pier would be removed, and a suspension bridge thrown over the gap, to keep open a communication for passengers, as goods would be landed or shipped in the proposed harbour. Boats could then pass from one side of the pier to the other, and make use of the north or south basin, according to the state of the weather.

19. For the reasons stated at length when the question of enclosed harbours was under our consideration, we cannot believe that the mouths of the proposed basins could be kept open by the aid of dredging, or that the surf would be sufficiently subdued to allow of boats of ordinary construction taking the place of the Masoolah boats.

20. Mr. Bell's project is to construct a break-water parallel to the shore in the line of the pier head, and to a length of about 400 yards. He estimates that a work formed of an outer casing of concrete blocks and a hearting of loose stone, could be built for R5,00,000; and that the pier could be protected from injury by means of guard chains. He would form the break-water itself into a quay, and thus give the port the advantage, of which it is most in want, of convenient means of shipping and landing cargo.

Mr. Bell arrived very recently in Madras, and cannot have acquired sufficient experience to allow of his drawing up a reliable estimate of the cost of the work he advocates. We consider it would be far more expensive than the existing pier, which cost R11,00,000, that to ensure its stability it would have to be of a much more massive construction than he contemplates, and that by its being within the limits of the shifting sand, it would be liable to favour the accumulation of spits at its ends.

21. Though we are of opinion that Mr. Bell's plan is ingenious and highly creditable to him, considering his very limited knowledge of the locality, we cannot recommend it for the approval of Government.

22. *Design by Colonel Orr and Mr. deClosets.*—There only remains then in our opinion one plan which is suitable to the circumstances of the case, that proposed by Colonel Orr and Mr. deClosets, *viz.*, a structure of rough stone on the principle of the Plymouth Break-water. The idea is by no means a new one. It was advocated repeatedly by Captain (now Lieutenant-General) Sir Arthur Cotton, K.C.S.I., and by the late Colonel deHaviland, a distinguished Officer of the

Appendix B.

Madras Engineers, so far back as 1836; and, even so late as ten years ago, when the screw pile pier was about to be sanctioned, Sir Arthur Cotton strenuously urged the construction of a break-water in preference. We do not forget that the work which was begun was confessedly a cover for boats only; but in his report, referred to above, Sir Arthur wrote:—

"what I have here said refers chiefly to the cost of a work of small extent, intended only for the securing of the landing, and not for covering the anchorage. If an extended work is undertaken (and I trust the subject will never be dropped again till Madras is as good a harbour as it is now a bad one) the method of calculating the cost will be different, inasmuch as it would then be worth while to execute any work that would facilitate the communication from the quarry to the break-water, "&c., &c.

And it has remained for Colonel Orr to bring the project forward in a complete form, and of a magnitude suited to the circumstances of the case; and we entirely acquiesce in the arguments advanced in his memorandum in support of that principle in preference to any other.

23. *Position of the break-water and its length.*—We accordingly beg leave to recommend that if the break-water is decided on, it should be constructed in a line parallel to the beach and at the distance of 1,200 yards from it, or 900 yards from the outer end of the pier, which will be in a little over seven fathoms depth at ordinary low water, and that the length be that proposed by Colonel Orr, *viz.*, 2,000 yards. As regards the distance to which the ends of the break-water should extend to the north and south of the point opposite the pier head, we are divided in opinion, three of our number advocating the adoption of the arrangement proposed by Colonel Orr, *viz.*, 1,200 yards south and 800 yards north of the pier, and opposite the Light-house and Railway terminus respectively, and the other four being of opinion that the distance on both sides should be equal.

24. *Section of the break-water.*—We consider that the section of the break-water proposed by Colonel Orr would be improved by continuing the exterior slope of 5 to 1 to a depth of about 15 feet below low water mark. In other respects we accept Colonel Orr's design for the section of the mass of the work. The wall on the crest, shown in dotted lines in Colonel Orr's sketch, we deem essential for the protection of the shipping, and we consider it would be built on the outer edge and joining the exterior slope in a curve.

25. *Splayed ends.*—The splayed ends proposed to be given to the break-water would, perhaps, facilitate the entrance of shipping, and also by causing a slight acceleration of the littoral current, serve to prevent the accumulation of sedimentary matter. If they are adopted, we recommend that their length and shape should be as proposed by Colonel Orr; but we do not attach much importance to them, and would advocate a decision regarding them being deferred until the rest of the work shall have been constructed.

26. *Source of supply of stone.*—We have very carefully considered the question of the source from which the material for the break-water should be procured, and in our investigation have compared the advantages of obtaining the stone from Palaveram, 10 miles from Madras; Seetanagrum in the Kistna District, 240 miles; Sholinghur on the south-west line of the Madras Railway, 55¾ miles; and Trittany on the north-west line, 50¼ miles; and we are led to give the preference to Trittany in consequence of its affording the necessary supply in a remarkably convenient form for economical quarrying, and because the means for conveying the stone to Madras by the Madras Railway are much superior to any other method which has been suggested, both as regards economy of time and certainty of supply; and although the estimated cost is considerably higher than that of stone obtained from other places, it has to be remembered, not only that the cost of conveyance is in one case a certainty, and in the others very doubtful, but also that the whole cost of the carriage, equal to half the amount of the entire estimated expenditure, will, by the employment of the Madras Railway as the means of transporting the material, be in one sense returned to Government, and go to reduce by the amount of profit on the undertaking the Government guarantee for interest.

27. *Mode of construction.*—We recommend that the stone should be carried, without breaking bulk, from the quarries to the end of a pier 300 yards in length, which should be constructed opposite the railway terminus, for the purpose of facilitating the delivery of the stone into boats, thence to be towed by the aid of steam tugs to the site of the work, and there deposited by cranes, care being taken to reserve all the largest stone for the outer portion of the work from a line 15 feet above the bed of the sea, while all below that line, as well as in the body of the work and for the inner slope, may be of small stones.

28. *Anticipated objections.*—Having now discussed the nature of the work we recommend, we think it advisable to anticipate objections which may possibly be raised against it, before we proceed to take the cost of the work into consideration.

I. *Silting of Harbour.*—The most natural objection would be that as there is a large bed of shifting sand, which is in constant motion by the surf and currents, the creation of a large area of comparatively still water inside the break-water, would lead to a deposit of sedimentary matter and the silting up of the harbour.

Our knowledge on this particular is as follows :—There is the wide bed of loose sand in constant motion, and the depth of which varies as much as 8 feet at the pier head, which is 1,010 feet from the shore, as evidenced by soundings taken along the side of the pier periodically for a series of years. We can form some opinion also of its extent by a comparison of the beach as it now is and as it was before stone groynes were thrown out some 12 or 13 years ago.

The European diver, who has walked all about the bed of the sea from opposite the Fort up to opposite the Railway terminus, and as far out as 11 fathoms depth, informs us that the loose sand extends as far as six fathoms only, beyond which the bed of the sea is stiff blue clay, with a small depth of firm sand over it, and he adduces, as evidence in support of his statement, the circumstance that while within the six-fathom line the height of the sand with reference to fixed articles, such as anchors, is variable, he has never found any variation at a greater depth, and as soundings taken under the orders of the Master Attendant while our Committee was sitting give the same results as the published chart by Lieutenant Sweny, of the late Indian Navy in 1859, there is very strong ground for believing that beyond the six-fathom line there is no sensible variation in the bed of the sea. And if that is the case now, there can be no cause for apprehending any variation after the construction of a break-water.

Transferred to the drawing which accompanies this report.

II. Extension of the foreshore.—We are of opinion that there will be a certain extension of the foreshore, which would adopt a more abrupt slope than it has at present, but that the capacity available for shipping, and the facilities for communication to and from the shore would thereby be increased rather than diminished.

III. Obstruction to currents.—The next objection that would probably be raised is, that in consequence of the break-water presenting a considerable surface at its ends in opposition to the current, spits of sand would form in prolongation of the line of break-water. This we consider would depend on the quantity and density of the matter carried in suspension by the currents which sweep past, on which point we have no certain information, but we are of opinion that very little silt is held in suspension, and that if such a spit did form during one monsoon, it would be removed during the next from the opposite quarter. There is not, so far as we are aware, any similar structure in the world erected under exactly the same circumstances, but happily we have near at hand, *viz.*, in the Armogum Shoal before mentioned, an analogous work formed by nature, which has created a vast area of comparatively still water, in exactly the same way as a break-water is intended and expected to act at Madras.

That shoal, which is 19 or 20 miles long, is distant 1½ miles from the shore at its southern extremity near Poondy point, and 5 miles distant at its northern extremity. The depth of water over the shoal is very variable, but in front of that part of the harbour which is marked as the anchorage, it is from two to four fathoms, the depth of water in the harbour being from five to seven fathoms. How this shoal was formed, we are unable to say, but it is a remarkable fact, and one which goes far to support our opinion that there would be no shoaling of the harbour at Madras, that so far from there having been any silting up of Blackwood's Harbour and its southern entrance, the soundings on the chart published in 1851, and corrected in 1864 at the Admiralty, are actually deeper than those on the chart dated 1821, and, so far as we know, there is no case of a channel between a rock, an island, or a sand bank, and the shore where littoral currents prevail, being silted up. The channel always remains, and on a small scale we have an example of a similar case at Madras, *viz.*, at the pier head, where, on account of a number of piles being clustered together, sand accumulates in large quantities. Deeper water always exists inside the pier head; and, on full consideration, we see no reason whatever to apprehend any injurious consequences resulting to the harbour either from silt carried in suspension, or from the bed of loose sand before mentioned.

IV. Surf not subdued.—Another probable objection would be that a break-water would not entirely get rid of the surf, and also that when a gale was blowing from the north a heavy sea would get up inside the harbour, which would imperil vessels at anchor: further, that ships could not ride out the violence of a gale even supposing the water was tolerably smooth. In reply to these objections we desire to state that we consider that a break-water, such as that proposed, would entirely free the shore of the surf which now impedes the landing and shipping of cargo, except for a limited distance from the points opposite the extremities of the work, and from the evidence of the majority of the nautical men whom we have consulted, we are of opinion that the shipping would be effectually protected from the heavy seas raised by the wind blowing across the Bay of Bengal, and that no dangerous consequences are to be apprehended from ordinary gales from north and south.

29. *Former objections raised to Sir Arthur Cotton's break-water.*—We further consider it desirable to note the objections which were raised on a former occasion, and which are recorded in Captain, (now Lieutenant-General Sir,) Arthur Cotton's letter of 18th November 1837.

1st.—That a stone break-water would be swallowed up in the sands.

2nd.—That it will be dispersed by the first hurricane.

3rd.—That it will not prevent the surf breaking.

4th.—It will cost an enormous sum of money.

5th.—It will collect sand about it and become connected with the shore, and the surf will form outside of it.

I.—We consider that the circumstances of the present proposal are so different to that of the boat break-water proposed by Sir Arthur Cotton and commenced in 1836, that there need not be the least apprehension under the first head. The boat break-water, at the time the stone was deposited, was only a little outside the line of surf, and in the bed of loose sand. From soundings now taken it appears that the heap of loose stones has completely disappeared, and that the soundings over the side differ very little from those in the neighbourhood. There can be little doubt that this is owing to the outer line of surf in ordinary weather having moved to the outside of the break-water, in consequence of the extension of the shore, which has been carried out by means of groynes, but the break-water now proposed being intended to be beyond the range of the loose sand, and where the bed of the sea is firm, will not be liable to undergo any subsidence which could injuriously affect the work.

II.—The cross sections proposed, and the size of the stones which it is intended to use in that part of the outer slope where the force of the sea would be greatest, are such as we confidently expect, will satisfactorily dispose of objection No. 2.

III.—We consider there is not the slightest cause for apprehension of any surf prevailing within the limits of the break-water, except for short distances opposite the north and south terminal points.

IV.—A million sterling is undoubtedly a very large sum to be expended on any one work not designed with the primary object of being of a remunerative nature, but when it is remembered that an annual revenue of £70,000 is to be expected, and that it is calculated on the *data* most unfavourable to the project, inasmuch as the tonnage of the shipping is taken at the very lowest estimate, and the rates of toll equally low, we venture to think that the work commends itself as a financial investment to favourable consideration, apart from the many other reasons advanced throughout this report.

V.—The difference of the conditions under which the break-water is proposed to be built, referred to under the head of objection No. 1, warrants us in expressing a confident opinion that no apprehension need be felt on this score.

29*a*. *Estimate.*—The cost of the stone being the heaviest item of expenditure, we will give the details of the cost from each place before framing one general estimate.

Seetanagrum, as estimated by Colonel Orr—

	R	a.	p.
Quarrying and loading on boat, per cubic yard	1	0	0
Carriage to Nizampatam, ditto	0	4	6
Transport from ditto to site of break-water, ditto	2	4	0
Total per cubic yard	3	8	6

and if to the above be added the cost of depositing the stone on the site, the cost per cubic yard will be increased to R3-12-9, which would give an average on the whole cost of the project of R5-14-0 per cubic yard.

From Palaveram the estimated cost is—

	R	a.	p.
Quarrying, per cubic yard	2	4	8
Loading on trucks	0	2	2
Transport to boats outside surf by a pier	0	9	6
Loading in barges	0	3	0
Transport to site of break-water	0	4	0
Depositing on site	0	2	0
Total per cubic yard	3	9	4

which would give an average on the whole cost of the work of R4-15-10 per cubic yard.

From Trittany the estimated cost is—

	R	a.	p.
Quarrying and loading per cubic yard	1	0	0
Rail carriage, 51 miles, at half anna per ton, and supposing weight of a cubic yard is two tons, will be per cubic yard	3	3	0
Loading on boats	0	4	0
Carrying to site and depositing	0	2	6
Total per cubic yard	4	9	6

or on the whole cost of the project an average rate of R5-10-0 per cubic yard. The area of the cross section, modified as we propose, is 912¾ yards, which for 2,000 yards in length will give as the cubical content of the whole work, with a uniform section 18,25,000 cubic yards.

Add enlarged space for the Batteries at each end	59,294⅞
Add content of sea wall	13,333
Total cubic yards	1,897,628

Detailed Estimate of Cost of Superintendence.

At the daily rate of 1,000 cubic yards, or 2,000 tons, of stone, which the Railway Company state they can convey without difficulty, and upon the supposition that this rate for the carriage and shipment of stone can be maintained during nine months out of the twelve, or, excluding Sundays, during 235 days in the year, the quantity of stone deposited on the site of the break-water during each year will amount to 235,000 cubic yards, or 470,000 tons. The whole of the stones ought, therefore, to be deposited within eight years of the completion of the shipping pier.

30. In calculating the cost of superintendence we assume that the work at the break-water will not be commenced until one year after the construction of the pier, and the operations at the quarry have been taken in hand.

Scale of superintendence.	Monthly Salary.	Allowance.	Total.
	R	R	R
Superintendent of Works	1,000	150	1,150
QUARRY.			
1 Executive Engineer, 2nd class	750	120	870
1 Supervisor, 1st do.	200	60	260
2 Overseers, 1st do.	200	90	290
3 do. 2nd do.	240	135	375
Apothecary and Dresser	...	...	150
Office Establishment	...	...	400
Per mensem	...	...	3,495
Per annum	...	...	41,940
For nine years	...	...	3,77,460

For the Break-water.

	Salary.	Allowance.	Total.
	R	R	R
1 Executive Engineer, 1st class	900	120	1,020
1 Sub-Engineer, 2nd do.	300	90	390
1 Supervisor, 2nd do.	150	60	210
2 Overseers, 1st do.	200	90	290
1 Superintendent of Steam Tugs and Barges . .	...	...	403
Office Establishment	...	...	300
Per mensem	...	...	2,610
Per annum	...	...	31,320
For seven years	...	...	2,50,560

Estimate of proposed Pier, total length 900 feet.

		Salary.	Allowance.	Total.
Iron Piling without Fenders for a run of 10 feet.		R	R a. p.	R a. p.
Wrought iron-work in piles	lbs.	15,288	150 0 0	1,023 12 0
Do. in braces, ties, &c. . .	„	7,840	0 1 3	612 8 0
Cast-iron work in pile heads, screws, &c. .	„	3,380	0 1 0	206 12 0
Teak timber	C. Ft.	168	3 8 0	588 0 0
Planking gangways	Sq. Ft.	120	0 10 0	75 0 0
Cost of screwing piles	No.	4	100 0 0	400 0 0
Carriage of materials	Tons.	16	2 0 0	32 0 0
Contingencies		...	...	293 0 0
				3,231 0 0
Fenders for a run of 10 feet not on T head.				
Teak timber	C. Ft.	216	3 8 0	756 0 0
Planking	Sq. Ft.	220	0 10 0	137 8 0
Wrought-iron work	lbs.	470	0 1 3	36 11 6
Driving piles	No.	3	150 0 0	450 0 0
Carriage of materials	Tons.	6	2 0 0	12 0 0
Contingencies	...	...	...	139 12 6
				1,532 0 0
Fender on T head for a run of 70 feet.				
Teak timber	C. Ft.	1,800	3 8 0	6,300 0 0
Planking	Sq. Ft.	1,540	0 10 0	962 8 0
Wrought-iron work	lbs.	3,290	0 1 3	257 0 6
Driving piles	No.	27	150 0 0	4,050 0 0
Carriage of materials	Tons.	43	2 0 0	86 0 0
Contingencies	...	...	...	1,165 7 6
				12,821 0 0

Cost of 20 feet of Permanent-Way.

			R a. p.	R a. p.
Rails	No.	2	22 13 6	45 11 0
Chairs	„	12	0 14 6	10 14 0
Wooden keys	„	12	40 0 0 Per 1,000	0 7 8
Fish plates	Pairs.	2	1 3 2	2 6 4
Do. bolts	Sets.	2	0 8 0	1 0 0
Iron chair bolts	No.	24	0 2 6	3 12 0
Carriage of materials	lbs.	1,440	2 0 0 Per ton.	1 4 7
Laying Permanent	Linl. Ft.	20	0 2 8	3 5 4
Contingencies		...	...	6 3 1
			Total	75 0 0

Estimate of proposed Pier, total length 900 feet.

820 feet of pier without fenders.		R a. p.	R a. p.	R a. p.
Cost of iron piling (a bay being 10 feet centre to centre) . . . bays	82	3,231 0 0	2,64,942 0 0	
Permanent-way for three lines of rails . . . . rail length	123	75 0 0	9,225 0 0	2,74,167 0 0
50 feet of pier with fenders.				
Cost of iron piling (a bay being 10 feet centre to centre) . . . bays	5	3,231 0 0	16,155 0 0	
Cost of fenders for a bay (do.) „	6	1,532 0 0	9,192 0 0	
Permanent-way for three lines of rails . . . . rail length	7½	75 0 0	562 8 0	25,909 8 0
70 feet of pier on T head.				
Total cost of fenders as per annexed estimate	...	......	12,821 0 0	
Cost of piling . . . . No.	7	3,231 0 0	22,617 0 0	
Four piles extra . . . lbs.	15,288	150 0 0	1,023 12 0	
Wrought-iron work in braces, ties, &c. . . . . . . „	3,441	0 1 3	268 13 3	
Cast-iron work . . . . „	2,602	......	162 10 0	
Teak-timber . . . .C. Ft.	34	3 8 0	119 0 0	
Permanent-way for two lines of rails .	7	75 0 0	525 0 0	
Turn-tables	6	2,364 0 0	14,184 0 0	
Foundations and fixing turn-tables .	6	2,000 0 0	12,000 0 0	63,721 3 3
				4,00,000 0 0

Abstract Estimate.

	R
1,897,628 cubic yards of stone quarried at Trittany, conveyed by rail to the end of a pier, thence by barges to the site of the break-water and deposited at R4-9-6	87,17,229
Special additional rate of R1 per cubic yard for one-tenth of the above . .	1,89,763
Special additional rate of R10 per cubic yard for the sea-wall	1,33,333
Plant, tools, &c.	2,00,000
Twenty barges at R4,000	80,000
Four steam tugs at R50,000	2,00,000
Shipping pier	4,00,000
Superintendence R3,77,460 + 2,50,560, say	7,00,000
	1,06,20,325

31. *Financial aspect.*—Not the least important point in connection with the break-water is whether, if made, the work will yield a fair return on the estimated cost, and we have taken some pains to obtain reliable *data* on which to form our opinion on this question; whether rightly or wrongly, there is no doubt that the impression among the mercantile community of Madras is, that the formation of a harbour here will attract trade that now finds other outlets, and that the yearly increasing extension of the Railway system in this Presidency will tap new fields of commerce *for the benefit of the safest and best sea-port on this or the other coast.* It is thought, at any rate during the south-west monsoon, when shipping operations at Bombay are difficult, and when importers and exporters will have (as in the course of a few years they will) in a large and rich tract of country the alternative railway systems of Bombay and Madras to choose from, that with a break-water at Madras no inconsiderable portion of the trade of Southern Central Provinces, like Dharwar, will find its way to this port. It is, moreover, a fact that Madras does not now import direct sufficient supplies of Home goods for its own consumption, and that Bombay and Calcutta are largely indented upon to make up the deficiency.

One of the reasons alleged for this, and it appears plausible enough, is that many ship-owners object to send their vessels to Madras on account of the bad reputation its surf and boatmen have, the delay in loading and unloading more than compensating, in ship-owners' eyes, for the comparatively trifling port-dues levied. Again, with reference to exports, there is a large and regular trade in cotton from Bombay to China, and it is within our knowledge that Madras cotton has this year been sent from Beypore to Bombay, and thence to China, the reason being that no direct opportunity offered. And it is further a fact that some large orders were not executed, as no ships could be obtained for the direct voyage. The inference drawn by the mercantile community is, that if Madras had a harbour, a greater number of vessels would find their way here, and trade would not be diverted or lost, as has been hitherto the case. But while thus incidentally referring to mercantile hopes, we have felt it to be our duty to confine our attention exclusively to the trade at present existing, and in considering the financial aspect of the break-water, to adopt no figures except those supplied by the Custom House records. In the Appendix I will be found a memorandum drawn up for the information of the Committee, showing the actual taxable trade of Madras, and it may be here noted that the only complaint against the figures therein is that they err, if at all, on being too small rather than too large. But this is an error which tells in favour of the financial aspect of the break-water, and we prefer that our report, in all its bearings, should not suffer from the test of time. The memorandum referred to has been circulated to the various mercantile firms in Madras, with a request that they would favour us with their views on the same, and all the replies received are to be found in the Appendix K.

32. It will be observed that one very important element in the subject now under consideration is the present cost of landing and shipping goods. The complaints of extortion, on the part of the Madras boatmen, not long ago attracted the attention of Government, and a Committee was appointed to enquire into the subject, and their recommendation was briefly that the legal rate of hire should, in future, be R2-8 per trip, instead of, as hitherto, R1-8. The Breakwater Committee has had the advantage (*vide* Appendix A) of examining a few of the leading merchants of Madras, and their opinion is unanimous that, even at the increased rate of hire, much inconvenience will at times be experienced, as before remarked. The doctrine of supply and demand does not seem to apply in its integrity to Madras, and the reason appears to be that the Masoolah boatmen are a limited and peculiar class of skilled labourers, who are monopolists, and whose only understanding of free trade is getting as much as possible for their work. When the pier was in working order the monopoly of the boatmen was rather interfered with, as the large boats plying to and from the pier did not require the same class of men as the Masoolah boats, and mere strength can always be had on easier terms than strength and skill combined. We therefore, with the knowledge of the comparative cost of the shipping and landing through the surf and at the pier, are able to arrive at an approximate idea of what importers and exporters will save when the surf no longer exists, that is, when the break-water is made. In calculating this saving, it is assumed that Masoolah boats will ply for the hire regulated by law, although the mercantile witnesses have no such expectation. On our assumption, it will be seen, from the Memorandum referred to, that at the very least the saving on shipping or landing goods will be from R1-4-0 to R1 per ton according to the class of boat employed. The saving will of course be so much the greater by every anna now paid to the boatmen in excess of the legal hire. As 382,500 tons of goods are at the least imported and exported to and from Madras, during the year, the mercantile community can, without adding a single pie to their present expenses on shipping and landing, contribute R3,82,500 to the income of the break-water.

33. It must not be forgotten either that the rates of insurance premium charged on goods to and from Madras are affected by the absence of harbour accommodation, and that all round insurance costs a quarter per cent. more to Madras than it does to Bombay. It is not an unfair inference that with a break-water Madras risks would be put on the same footing as those to and from Bombay, and as the annual value of the Madras import and export trade is about R5,00,00,000, excluding specie, the savings to merchants in the item of insurance alone would be R1,25,000. In this calculation the additional monsoon rate of half per cent., charged from 15th October to 15th December, is not included, but even without this it is found that in boat-hire and insurance the trade at present pays R5,07,500 per annum, which a break-water would save it.

34. It is, however, very obvious that if the advantages to be gained by goods are great the benefits to be conferred on the vessels carrying these goods are in every sense much larger. Besides the material advantage of having a safe anchorage provided for them, a fact that will tell considerably in the item of their insurance, there is the further great gain in time in discharging and loading—a gain the value of which it is impossible to estimate, as besides the

saving in ship's actual expenses, it not unfrequently happens that the chance of a good freight is lost, through the ship not being ready for it, on account of her inward cargo being taken out so slowly. Besides, although it does not quite come within the scope of this portion of our report, it must not be forgotten that the Madras surf claims as its victims lives as well as property, and a diminution of such risk will be the inevitable effect of a break-water. But, confining attention to the purely financial view, it will be seen that for absolutely no return whatever, except the permission to let down an anchor in the roadstead, vessels of every class and size are charged 3 annas per register ton. This charge is considered moderate, even although nothing is given for it, and we are of opinion that greatly enhanced port-dues would be cheerfully paid if a safe and commodious harbour, such as the break-water would give, were provided.

35. It is not so much a question of increasing advantages to shipping as of creating them, and from all we can learn we infer that ships would gladly pay four or five times the present port-dues if a harbour were made. The shipping visiting Madras consists of three classes: steamers, ships, British and foreign-owned, and native craft. The aggregate value annually may be taken at about R30,000,000, and the gross tonnage is on an average as under—

	Tons.
Steamers	146,000
Ships	119,000
Native craft	39,000

These figures represent the shipping of Madras alone. No account is taken of the enormous trade to and from the subordinate ports of the Presidency—a Presidency which along its entire range of coast, with the exception of Cochin, has no harbour of refuge. If the sea-borne trade of the entire Presidency is taken into account, the following significant statistics are obtained for the ten years 1857 to 1866, both inclusive:—

	Vessels. No.	Tonnage.
Madras Presidency, Entrances and Clearances	34,889	9,972,421
Bombay do. do. do.	12,084	9,213,192
Bengal do. do. do.	23,111	13,724,556
Burmah do. do. do.	8,066	3,682,100

Madras, therefore, in the number of its craft far surpasses the other Presidencies, and in its tonnage is only second in importance. But we cannot, of course, in estimating the income of the sole harbour that would be in the Presidency, deal with any save the purely local trade of Madras, although it is a question worthy of consideration whether a break-water ought not in a small degree to be supported by the shipping that might avail of it, if circumstances compelled. The Channel Light in England and the Basses Light on our coast are cases in point, where vessels pay for what they hardly ever make any use of. But we have at present to do with the Madras trade only, and we find that ship owners will save in insurance and time, when the break-water is made, a sum that will justify a very large increase to the present port dues. In the memorandum in the Appendix will be found an estimate of the various incomes, at differing rates, that the shipping will contribute. We are of opinion that, considering the short time steamers are likely to avail themselves of the harbour, their port-dues should be less onerous than those charged for native craft and ships. Again, as native craft are less valuable, and visit Madras more frequently than long-voyaging ships, it seems reasonable to tax the former less than the latter. On the whole, we are of opinion that the highest rates shown in the Memorandum might equitably be charged, and the income from shipping would then stand as under:—

	R
Steamers at 8 annas per ton	73,000
Native craft at 12 „ „	29,250
Ships at 16 „ „	1,19,000
TOTAL	2,21,250

36. The result, then, of our investigation into the financial aspect of the break-water is that an income, with no hardship to the trade, can be obtained of—

R 5,07,500 from goods.
„ 2,21,250 from port-dues.

R 7,28,750

37. The next point to be considered is how the income from goods can best be collected. In the Memorandum in the Appendix it will be seen that a rate per ton or per package only is

contemplated, but we are disposed rather to adopt the suggestion in some of the letters from the merchants of Madras, and to recommend that an *ad-valorem* duty should be levied. The present machinery of the Custom House would be available for this purpose, and one per cent. on the value of imports and exports would give R5,00,000 per annum, or rather under what the trade now gives away to underwriters and boatmen. It cannot be too strongly insisted upon that the proposed tax of one per cent. is no additional burden to trade: it is simply a transfer, for the benefit of trade, from one class of charges to another, and for all the collateral advantages expected to flow from the construction of a break-water, trade will be called on to pay nothing whatever.

38. Before leaving this portion of our report, we think it desirable to meet one or two points laid stress on by the mercantile firms in the letters which will be found in the Appendix.

I.—The first is the frequency with which the break-water dues on shipping should be levied, that is, how often the same vessel should pay in one year. In our opinion this is a matter of detail, which will be more properly settled when a bill for regulating the dues is under the consideration of Government.

II.—The next is with reference to the grouping of the ports of the Presidency, sanctioned by an Act of last year, and the consolidation of all the port funds into one general fund. It is obvious that the construction of a break-water at Madras would destroy the conditions existing when that Act was passed, and would necessitate a new grouping, from which Madras must be excluded.

III.—The third and last point is the purely local view taken in the Memorandum in the Appendix of the sources from which the income of the break-water is expected to come. It does not seem to us to be within our province to adopt any other save the purely local view complained of, and as that view shows a fair return on the estimated cost of the break-water, the broader and more Imperial view, if adopted, will only add strength to our conclusion that in a financial aspect the break-water must be an assured success.

39.—*Agency for the construction of the break-water.*—It now only remains to consider the question of the agency whereby the construction of the break-water should be carried out. We are unanimously of opinion that a work of such Imperial importance should not pass out of the hands of Government. There is no doubt a Company could be formed to carry out the work, but it is further certain that Government would, in the first instance, have to guarantee an interest of five per cent. Government itself can easily borrow on these terms, and as the borrowing might be extended over the eight or ten years required to complete the break-water, the drain on the Imperial funds would be very trifling, if any at all, for, so soon as the work had made any progress, some increase of port-dues and charges on goods might very fairly be made, and these would pay the interest on the borrowed monies. Public Works Debentures bearing interest at five per cent., and redeemable at the pleasure of Government out of a sinking fund formed from the profits of the break-water, appears to us the best and the least expensive mode of raising the funds for this great and important work.

40. Before closing our report we beg leave to submit a few general remarks in support of the conclusion at which we have arrived. If it were possible to construct an enclosed harbour, which should be secure from the danger of shoaling up, we should not hesitate to recommend it in preference to a break-water. It would be greatly superior to the latter in every respect. The piers would be constructed from the shore, and at far less expense, in proportion to the material used, than the break-water; the accommodation for shipping and the facilities for landing and shipping cargo, would be greatly superior to those afforded in an open harbour. But we consider that all these advantages would be rendered nugatory by the shoaling of the harbour, which would certainly result from the construction of any solid piers or groynes from the shore, and we are strongly of opinion that a break-water is the one work from which any real improvement is to be hoped. It will not afford a perfect harbour—no break-water does—but it will effect an immense improvement on the present exposed state of the roads. The cost of the work must necessarily be very great, and although we have endeavoured to arrive at an accurate knowledge of the rates at which the mass of material can be deposited at the required site, we are fully alive to the imperfection of any data which are not derived from actual experiment. In this case extensive operations would be necessary before the actual working rates could be established, for there is no example of quarrying, on the scale which would be necessary for the break-water, in any part of the Presidency. Even at the large anicuts in the Godavery and Kistna Deltas, stones of five tons weight have been used only exceptionally, while a large portion of those required for the break-water would have to be in excess of this weight. Moreover, the larger stones used on the Kistna works were mainly rolled down from the quarries to the edge of the river, and transferred to boats without the aid of cranes. On the other hand, at

the Trittany quarries, which we have selected as our source of supply for the break-water, every large stone would have to be lifted by a crane on to the railway wagons. This would necessitate the laying of rails close up to the stones, and bearing in mind the destruction of plant which would be liable to be produced by the blasting operations, and the constant shifting and clearing of rails, &c., we think it not improbable that the rate allowed for the mass of the stone-work will be found insufficient, and that in practice R2 per cubic yard will more accurately represent the cost than R1, and this, notwithstanding the very favourable character of the quarries, and the extensive supply of rough stone blocks, chiefly trap (or whinstone), with which the crest of the hills is crowned.

41. It is also very doubtful if our Committee have correctly estimated the time to which the operations would extend. The railway authorities can indeed give us an assurance, which we feel can be fully relied on, of their ability to convey from the quarries at Trittany to the beach at Madras 2,000 tons per diem. But this involves the ability on the part of the quarry establishment to load that quantity daily, and of the boat establishment to unload, and convey it to the site of the break-water. Looking to the long period for which the Plymauth Break-water was in operation, and the slowness of the process of advancing the works at Portland, notwithstanding the great facilities that exist for conducting material rapidly to the site, we are constrained to doubt the possibility of completing the works at Madras in a period of eight years, though not having data to guide us in arriving at a more accurate calculation, we have thought it not unreasonable to assume that what the railway can do in addition to its ordinary traffic may also be done at the quarries, and by the boat establishment at Madras considering that the actual distance to which the material would have to be moved at the two places is very insignificant. As we have already remarked, it is the certainty of the conveyance of the material by the railway at specific rates, both as regards the cost of transit and the quantity to be conveyed in a given time, that has in a great measure induced us to give the preference to this source of supply over the other two—at Seetanagram and Palaveram,—for, in regard to both of these, the calculation of the cost of conveyance of the material must be hypothetical throughout, while the risk of delay, arising from the greater distance to which the transport by sea would extend over and above any period that might generally be allowed to be reasonable, must evidently be much greater than in the case of the mere transfer of the stone from the end of a pier connected with the railway to the line of break-water a few hundred yards in advance.

42. Our estimate amounts to R1,06,20,325. In it we have made no deduction for the interstices between the stones, for although the space left unfilled will form a very considerable fraction of the whole volume of the work, we recognise the neces-ity of providing a large surplus to make good wastage, by the dispersion of some of the smaller material during the progress of the work, or before it should have become fully consolidated, as well as by the subsidence of the stone in the bed of the sea, which, though not likely to be considerable as regards depth, will still take place to a certain extent along the whole width of the base or the broadest part of the work. We consider, however, that in calculating the contents of the break-water as solid throughout, we make a very ample provision for contingencies of this nature. But as regards the additional cost which would be entailed by a higher rate for quarrying than we have allowed, and by an extension of the period during which the works would be in operation, we can only recommend the Government to be prepared for the possibility, if not probability, of our estimate being exceeded by nearly as much as 25 per cent., that is, of the total cost rising to 1¼ millions sterling.

43. If the works succeed in answering the expectations we have formed of them, we do not think the amount we have mentioned need be considered exorbitant. The great advantages which would be secured to all interests connected with the port have already been fully explained, but we have, perhaps, hardly laid sufficient stress on the very important bearing which a cheapening of the charges for boat-hire at Madras would have on the agricultural revenue of the Presidency. The Government are aware that a number of districts around Madras, *viz.*, the Madras District itself, North Arcot, Salem, Bellary, Cuddapah, Kurnool, and Mysore, and all connected with Madras by the south-west and north-west lines of railway, are subjected to a frequent recurrence of drought, with its consequent dearness and scarcity of food, and distress among the population. A great part of all the districts we have specified are dependent on their supply of water on the north-east monsoon, which is of short duration, and of a very uncertain character. The great importance of the line of railway in conveying food to the inland districts was exhibited during the year before last (1866), and must be fully appreciated by the Government, but as Madras itself is liable to suffer from a scarcity of food, the requisite supplies must be drawn to it mainly by sea from the other districts along the coast, where the cultivation is of a more certain and abundant character. The Government are

deeply interested in the extension of irrigation throughout the Presidency, and especially in the Northern Deltas, where a vast extent of land and unfailing supply of water are available, but the price of grain imported to Madras from Cocanada andMasulipatam is swelled to such a high figure by the heavy transport and boat charges, that this traffic, which deserves encouragement in every possible way, is very seriously impeded. As the Masoolah boats at Madras carry only 1½ tons, a charge for conveying this quantity of grain across the surf, of Rs 3 or 4, a sum very commonly paid, is a serious addition to the price. If the charge were reduced, the imports of rice and other grain would certainly be increased, and by thereby gradually creating a certain market, instead of an uncertain one, the improvements of the Madras harbour would have a very beneficial effect on the land-revenue of distant districts, would allow of a higher rate being paid by the people than they could otherwise afford to give, and would also lead to an extension of the cultivation. It is on this ground that while fully acknowledging the perfect right of Government to impose additional port-dues to compensate themselves for the large outlay required for the construction of a break-water, we consider that it would be sounder policy for them to look to an increase of the land-revenue, and to the general improvement of the country which would accompany it, as the principal source from which a remunerative return from the work should be derived.

44. As we have entered at some length into a consideration of the probable result of any attempt to construct a closed harbour at Madras, it may be advantageous to give an opinion more fully than we have yet given it, on the extent to which silting would be induced by a break-water; the more so as in one of the projects* for a work of that nature which have been placed before us, special provision has been made for preventing the shoaling of the anchorage.

* Mr. Doyle's.

45. The following remarks, descriptive of the process of silting, assuming the worst case possible, have been offered for our consideration :—

"Suppose that the littoral current, say from the south, carries matter in suspension, and that it deposits it in the comparatively still water at the north extremity of the work, and it may be to a certain extent at the south end also. So long as the current should preserve the same direction, there would be no tendency in these deposits to diminish, but, on the contrary, seeing that they would merely serve to add to the bulk of the break-water, there would seem reason to apprehend a gradual extension of the spit. If, however, the action towards the shore produced by the *swell* should have the effect of removing the whole or any portion of the deposits nearly as fast as they formed, it would depend on the extent to which the littoral current should be charged or loaded with silt, whether it would or would not have the power of taking up and conveying away from the vicinity of the work the additional quantity of matter thus placed in contact with it.

"On the other hand, if the sand or silt which has been supposed to accumulate in prolongation of the break-water were to remain undisturbed till the setting-in of the opposite or north-east monsoon, it may be presumed from the direction of the wind and currents, and from the violent action of the sea during that season, that the sand would be removed from its place, and be carried into the comparatively still water between the line of break-water and the shore; so that the possibility has to be contemplated of all the sand or silt which is deposited during the south-west monsoon in continuation of the break-water, being bodily transferred to the rear of it. The question then arises as to whether the succeeding south-west monsoon would have the power of removing that accumulation, and of carrying it, in the main, away to a distance, in addition as it were to its ordinary duty. It seems reasonable to entertain doubt of such a result occurring. The current comes to the spot with a certain quantity of silt in suspension,—can it take up fresh matter without depositing what it had carried before? The natural action would be to form a new spit in prolongation of the break-water, similar to that supposed to have been formed during the previous season. What ground is there to infer that the extent of the spit, during the second season, will be limited to the same amount? It may be argued that the contraction of the passage (by the shoals supposed to have been formed in rear of the break-water) between the break-water and the shore, would cause an accession to the velocity of the littoral current, but it has to be remembered that the case is entirely different from that of the water-way of a channel which may be contracted by a bridge or other obstruction. In the latter a certain quantity of water *must* pass down the channel, and if the water-way is contracted one-half the velocity will be doubled. But in the case of break-water it is not *necessary* that the same quantity of water should always pass between the break-water and the shore, and if the obstruction (by shoals) is so great as to render it *easier* for the current to pass round the end of the break-water and along the outer face, in preference to the inside of the break-water, there would be nothing to prevent its taking that course. Any obstruction in the bed of the sea between the break-water and the shore would have a tendency to deflect the current in the manner described, and of course, if such deflection came into operation, the formation of fresh deposits would be promoted."

46. In reply to the above observations we would remark, after attentively considering the whole subject, that the assumption that the littoral currents everywhere do carry sedimentary matter in suspension with them, as they sweep along the coast, is not borne out by facts. There is, on the contrary, strong ground for presuming that the movement of solid matter along the coast in the vicinity of Madras is confined almost entirely to the sand which lines the beach, and which, as we have explained in a former page, extends in the form of a loose shifting bed to the distance of 700 or 800 yards from the shore, or to where the depth is between five and six fathoms. Beyond this limit the bed of the sea is firm, and exhibits no

signs of having been subjected to any change since the date at which a chart of the roads was first drawn up. To what extent the current along shore, which, according to the observations of a late astronomer, attain the maximum velocity of three knots an hour, are capable of lifting the sand without the aid of the disturbing effect of the surf and waves, we have no means of ascertaining; but we know that the sand is moved backwards and forwards along the coast, that the beach at certain points is worn away, and that the process may be arrested, and the beach extended at will, by the construction of groynes. That the proposed break-water would have the effect of checking whatever lifting of the sand is due to the action of the surf opposite the work, cannot be disputed, if, as we anticipate will be the case, the surf itself will be almost entirely annihilated; and we also admit, as we have before stated in paragraph 27—II, that a certain accumulation of sand would be formed in advance of the present beach, but we consider that the neutralization of the lifting action of the surf, and of the aid it now affords to the removal of the sand, would be compensated by the additional power gained by the current, consequent on the removal of the deflective action of waves and surf upon it. On this point we can afford no absolute proof, but we can point to the Armogum Shoal for a confirmation to a great extent of what we have advanced; for we have there a long spit, which at the same time protects the shore opposite to it, and prevents the formation of a violent surf, like that which prevails in the Madras roads, while it has not served to shoal up the channel between it and the shore, a fact sufficient in itself to show that the littoral currents carry the sand onwards through that channel.

Mr. Taylor.

As regards the possibility contemplated of the formation of spits in prolongation of the break-water during the south-west monsoon, and of their removal during the succeeding north-east monsoon to the landward side of the work, we would explain that the sea is habitually clear in the anchorage, as every one who has frequented the place must have observed, and that even along the pier side, where there is always a considerable agitation of the sea, objects can be distinguished at a depth of some feet below the surface. This is so totally different from the condition of any river which traverses an alluvial tract of country, that we cannot but think that any parallel drawn between the action of a break-water and that of an obstruction of similar form in a silt bearing river, is altogether out of place. It may be convenient to show what would be the probable results if the marine currents were everywhere loaded with silt or mud—but as we know that the bed of the sea beyond five or six fathoms depth is not liable to be disturbed by the action of either the waves or currents, and as, moreover, there are no large rivers within a distance of many miles from Madras, we do not admit the possibility of there being alluvial deposits to any appreciable extent, either in continuation of the break-water or between it and the shore. Such rivers, moreover, as fall into the sea along the east coast, are made use of to so large an extent for the irrigation of the country, that, with the exception of the Godavery and Kistna, which are too remote to affect any work at Madras, the volume of water they discharge into the sea is quite insignificant. The break-water would occupy a position not dissimilar to that of rocks, which are to be seen detached from the shore at various points along both the eastern and western coasts; and on reference to the charts, it will be found that they have not materially affected the depth of water between them and the shore.

For the above reasons we consider there is no ground for apprehending any injurious shoaling of the proposed harbour, either from sand or silt.

47. We have now only to furnish Government with some particulars of the damage and loss of life which have resulted from storms in or near the Madras roads. The Superintendent of Marine has prepared a statement of the total or partial wrecks which have occurred from the year 1842 to the year 1865, and for information regarding the hurricanes of the century preceding the former year, we have referred to Pharoah's Gazetteer of Southern India, in which there is a very complete and interesting account of all the great storms to which Madras has been subjected. The first on record occurred on the 3rd October 1746. Of the six large French ships in the roads, three put to sea and foundered with the loss of 1,200 men, and the other three were dismasted. Two other ships, prizes, were wrecked, and of twenty other vessels in the roads, not one escaped, all being either wrecked on the spot or lost at sea. Another hurricane occurred off Cuddalore, on the 13th April 1749. Two men-of-war, one a 74-gun ship, were wrecked with the loss of 850 men. Two other ships, and all the small vessels that were near Fort Saint David, were likewise wrecked. Two other great hurricanes occurred in 1752 and 1761. In the last the British squadron, consisting of eight sail of the line, two frigates, and two other ships, suffered severely. Three of the ships came ashore, and three others were lost with their crews, numbering about 1,100 men.

48. In the hurricane of 21st October 1773 all the vessels that remained at anchor were lost with their crews: upwards of 100 country vessels were stranded on the beach.

49. There was a heavy gale on the 27th October 1797, others on 4th December 1803, and 10th December 1807, and on the 2nd May 1811. In the last the "Dover" frigate and a store ship were lost in the roads, and ninety country vessels went down at their anchors. Hurricanes occurred again on the 24th October 1818, 9th October 1820, and 30th October 1836.

50. In 1842 there was a heavy gale, but hardly what would be considered a hurricane. In it seven vessels, of an average tonnage of 260 tons, were wrecked, with the loss of seventeen lives, and with a loss of cargo estimated at nearly three lacs of rupees. Hurricanes again occurred in May 1843, on 25th November 1846, in March 1853, May 1858, and on the 25th November 1865. The number of vessels wrecked since 1842 amounts to forty-two, their average tonnage to 480, and the loss of life and property to 196, and thirty-eight lakhs of rupees nearly, but this does not include the loss to the country craft, which is likely to have been fully as great, nor that of vessels wrecked off Pondicherry and other ports along the coast.

51. It would thus appear that Madras is subjected to severe hurricanes about fifteen times in a century, or once every six or seven years, and that the average annual loss sustained by the owners of large vessels alone, exclusive of their valuable cargoes, amounts to about 1¾ lakhs of rupees. But the dispersion of such vessels as are not wrecked during the gale, the serious damage they are liable to sustain, and the derangement of trade which must be the result of the present system of warning vessels to put out to sea when the weather assumes a threatening appearance, are alone sufficient to show the great necessity that exists for trying to introduce some improvement in the present exposed condition of the roadstead. The improvement or formation of harbours has been found necessary by every civilized country that has a trade to support. While so much has been done, or is in progress, for the development of the resources of this Presidency, we feel satisfied that Government do not need arguments from us to convince them that the large sums which are being expended annually on railways, canals, and other important works, cannot be productive of really satisfactory results unless active measures are also taken for the removal of the difficulties which beset trading operations along the coast. It is impossible for us to judge of the extent to which the trade of Madras is capable of being increased if it possessed a safe and convenient harbour; but we know that it is now terribly impeded by the total absence of any shelter for shipping, and of any facilities for the landing and shipping of goods. We feel satisfied that something will have to be done sooner or later to supply these wants, and past experience of harbour improvements shows that nothing short of the heavy outlay we contemplate is likely to be successful.

(Signed) J. C. ANDERSON.
(„) H. D. E. DALRYMPLE.
(„) R. B. ELWIN.
(„) J. H. M. SHAW STEWART.
(„) P. MACFADYEN.
(„) B. ANDERSON.

Minute by COLONEL J. CARPENDALE, R.E., President of the Committee,—dated 15th January 1867.

As I do not concur with my colleagues in much of the above report, it is necessary that I should record my own opinion on some points separately.

2. Taking the word "silt" as used in the report to mean something distinct from the shifting bed of loose sand along the shore, I am not aware of any reason for the opinion that any "silt" is held in suspension, and is carried north and south by the littoral currents, and I would have no fear whatever of any shoaling of the harbour from such "silt" in the event of the break-water being constructed.

3. In regard to the loose bed of sand, we have it in evidence of the European diver that it does not extend beyond a depth of six fathoms, which depth is at a distance of about 800 yards from the shore. By soundings taken along the pier for a series of years, it is known that the depth of sand at the pier head varies as much as eight feet at different seasons, and that when there is an increase of sand there, the quantity at the shore-end of the pier is much reduced and the water considerably deeper; also, that as sand accumulates at the shore, it is washed away at the pier head, from which I infer that the movement of the body of loose sand is chiefly out to sea and in again to the shore, and I am not aware of any grounds for the belief that this sand is carried to any considerable distance by the littoral currents, though we know by the effect produced by the groynes on the beach that the sand is moved to a short distance north and south, and I am not prepared to assert that, this being the case, the construction of

a break-water would not lead to a considerable shoaling up of the harbour inside, perhaps as far as the present six-fathom line. I do not go so far as to say that I expect such would be the result, but I feel great doubt in the matter, and I do not consider the circumstances of the Armogam Shoal sufficiently analogous to warrant a confident expression of opinion that no injurious consequences need be apprehended from the construction of a break-water parallel to the shore.

4. As regards the length of 2,000 yards for a break-water, I consider that for so great a distance as 1,200 yards from the shore the length is insufficient, and that, to afford sufficient shelter to the shipping at the north of the pier, it should extend fully three hundred yards north of the railway terminus: also that, if the protection of Black Town and the defence of Fort St. George is taken into account in weighing the advantages of the project, that defence should be complete, which it certainly would not be with one battery only to the south at a point opposite the Light-House or the office of Messrs. Parry and Co. In the event, then, of such a work being sanctioned, I would consider it necessary that at the same time another battery should be erected 1,200 yards in advance of a point midway between the Fort and the Marine Villa, by means of which, in conjunction with the batteries at either end of the break-water, Black Town would be admirably protected, and Fort St. George, whose Arsenal barracks, and other public buildings are not now in the smallest degree protected from the fire of an enemy's vessels, would be secure from any attack from sea except in the extreme case of an enemy running in at night between the batteries.

5. I am, however, after long consideration, more in favour of a close harbour as proposed by Mr. W. Fraser and Mr. Samuel Perkes; as before stated, I do not believe that the loose sand in the beach is conveyed to any considerable distance by the littoral currents. It is remarkable to what a limited extent the groynes on the beach, although constructed within the limits of the shifting bed of sand, effect the object for which they were built, and that their ends always remain uncovered, the very fact of the necessity for their construction is strong evidence that the natural operation of the sea here is to erode the coast, not to extend the beach. I believe, if a close harbour was formed, the mouth of which would be in seven fathoms water, that no silt or sand whatever would pass the mouth or enter it, and that there would be no necessity for dredging; sand, no doubt, would in one monsoon accumulate to what may be called a large extent outside the harbour and against the dyke forming it, but with the change of current in the alternate monsoon it would be washed away again. A close harbour should embrace the Railway station and the Fort, and would probably not cost more than half a million: all the interior accommodation of piers, wharf, &c., which are proposed in some of the projects, I would consider needless, but a break-water inside the harbour, and 150 yards from the mouth, might prove to be necessary, to keep out the swell of the sea for a few days in the year.

6. I would, therefore, advocate a pier of rough stone of large dimensions being thrown out for a distance of 500 or 600 yards, starting from a point 300 yards north of the railway terminus, and running in a direction south-east by south. It can do no harm, and it will very soon be apparent whether or not it arrests sand in such large quantity as to confirm the opinion that if a close harbour was formed it would, in course of time, silt up.

(Signed) J. CARPENDALE, *Colonel, R.E.,*
President of Committee.

Order of the Madras Government on the above reports, &c., admitting the necessity of providing Harbour accommodation, and submitting the whole project for the favourable consideration of the Government of India,—dated 17th March 1869.

The Government have perused this report with the greatest interest,and being satisfied of the impracticability of any scheme being devised for the formation of an enclosed harbour at Madras that shall be free from the objections which appear with good reason to be urged against the construction of jetties or training walls projected seaward from the beach, they accept the conclusion at which the Committee have arrived that the only feasible manner in which improved harbour accommodation for shipping can be provided, and the difficulties to the landing and shipping of cargo which is offered by the surf can be overcome, is by the construction of a break-water. A work of that description placed at about 1,200 yards from the shore in seven fathoms of water at low tide and parallel to the line of the coast will, it is believed, create a sufficiently secure and sheltered anchorage with comparatively smooth water and no surf between it and the beach. This, the Committee think, is all the improved harbour accommodation which the circumstances of this coast are calculated to permit of being provided.

2. The Committee are of opinion that the formation of a break-water in the position indicated is perfectly practicable, and, for reasons which the Government consider well founded, they recommend that the work should be made on the rough stone, or "pierre perdue" system, which, requiring little more than the deposition of large masses of rough stone, has been found a successful mode of constructing such works; and they suggest that the railway be employed in transporting the stone from Tritany (fifty and a half miles from Madras), from whence it might be readily obtained. Basing their estimate on the proposal to procure the stone from this source of supply, and calculating that for every yard in length 912⅜ cubic yards of stone will be required, the Committee estimate the total cost of the work at R1,06,20,325, allowing amply for superintendence, plant, and other charges.

3. The Government are fully alive to the great disadvantages under which this Presidency labours in having at its chief city and principal centre of trade no harbour accommodation of any description, and concurring generally in the views of the Committee, His Excellency in Council believes that no time should be lost in setting on foot such measures of improvement as may be found practicable and are essentially necessary to prevent the possible diversion which is threatened of trade from this coast to a western outlet. His Excellency the Governor in Council accordingly resolves to submit the whole subject, as presented to this Government for the favourable consideration of the Government of India, in the hope that it will meet with the support of the Right Honourable the Governor General in Council, and that the Secretary of State may be moved to send out a thoroughly qualified marine and harbour engineer to examine and report on the feasibility of carrying out such measures as may be necessary for the improvement of the port by the construction of a break-water, or in such other way as may appear to be most practicable.

Appendix B.

Memorandum by COLONEL A. ORR, R.E., on the proposed break-water,—dated 4th September 1869.

The disadvantages under which Madras labours in possessing no natural harbour in which vessels may anchor in safety, and load or unload their cargoes in smooth water, being more and more felt as the trading interests of the port have grown into importance, several schemes have at one time or another been suggested for the formation of an artificial harbour on or within the foreshore, but having all been designed on a principle of construction requiring the projection from the beach of long training walls or jetties into the sea, none of them have been free from the serious and seemingly fatal objection which attaches to any description of work which should interfere with the littoral currents that prevail on this coast. It is evident to all who have had opportunities of studying the circumstances of the Madras beach, that any obstruction opposed to the currents must necessarily have the effect of arresting the passage of the sand, which is in constant movement by the combined action of the surf and those currents, and of causing it to accumulate to windward of the obstacle. This accumulation would, at first, form merely an extension of the beach seaward in the angles between the training walls and the shore; but it would ultimately, I have no doubt, carry the line of the coast to the outer end of those walls and close the entrance between them. This view of the action of training walls, or of a jetty projected into the sea, is practically confirmed by the manner in which a groyne on the foreshore, by being lengthened or shortened, can be made to extend or diminish the beach in its neighbourhood, and even the open structure of the pier is believed to have the same tendency.

2. This great liability to silt, and the want of a rise and fall of tide of sufficient height to give the means of creating a natural scour for its prevention or removal, are difficulties which seem not likely to be easily overcome in forming an enclosed harbour anywhere on this coast, but they offer no difficulties to another mode in which, although a completely enclosed and sheltered harbour, absolutely safe at all times and capable of affording wharf accommodation to shipping, cannot be formed, there may be obtained the next best thing—a sheltered and comparatively safe, though open, anchorage, with smooth water between it and the shore.

3. Such an anchorage can, I have no doubt, be made by the construction of a detached break-water of a form to effectually intercept the highest waves, and of a length to give the requisite anchorage space, as well as to make smooth water on a sufficiently large portion of the beach. A scheme of this nature has lately been brought forward by Mr. deClosets, a

French engineer, and I believe it is both feasible and practically likely to afford Madras all the advantages of the best harbour which, in a physical point of view, it is possible to make on this open coast.

4. Mr. deCloset's plan is to construct a break-water parallel to the beach in seven fathoms at high water, and about 2,000 yards in length. A break-water thus placed will be so exactly in the direction of the current as to offer no obstruction to it, and, therefore, arresting no sand, would have no tendency to cause silting to take place in any direction, while at the same time, being at right angles, or very nearly so, to the direction in which the swell travels, it would effectually break the force of the sea, which, as any one may have observed who has ever watched it from the head of the pier, rolls in towards the land at an angle very little inclined to the line of the coast, from whatever direction the wind may be blowing. Thus, a break-water parallel to the coast will be placed in the best position to afford the necessary shelter, and to produce smooth water along its whole length and extending to the beach. Another favourable circumstance is the remarkably regular manner in which the bed of the sea shelves, as on that account, and because the wind, during the storms that occasionally visit the coast, never blows for any length of time in one direction, there is not sufficient depth of water nor time for the seas to be raised to any great height, and the waves cannot acquire anything like the force of those which have to be withstood by sea defences constructed on the abrupt and exposed coasts of England. This, as well as at the other circumstances of this coast, appear in fact to be peculiarly favourable to the formation of a break-water, and though the construction of such a work, in 42 feet of water in the open sea, must necessarily be a costly undertaking, it is surely not beyond the resources of a Government which, spending vast sums annually on roads, railways, and other works directly tending to increase the commerce and importance of the port, is further bound, by every humane as well as political consideration, to provide a harbour of refuge for shipping on this dangerous coast, where it may be easily shown that, during the last half century, the loss of property in wrecks, to say nothing of life, has been far in excess of any amount of money that may be required to form a safe and accessible anchorage in the manner now suggested.

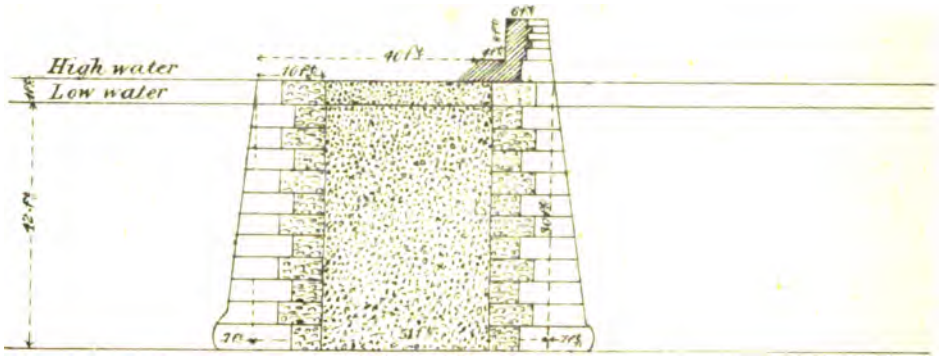
5. A break-water may be formed in several ways. It may be made of stone or blocks of beton either thrown in rough or built up regularly from the bottom of the sea by means of diving apparatus; or it may be formed by sinking caissons filled with concrete or rubble masonry; or may be constructed on the system of screw piles supporting wave screens made in the manner of louvre boards.

6. The employment of screw piles for the purpose has been successfully adopted at the Port of Blyth in England, and they may be suitable in some localities, or where the work is to combine the character of a break-water and a jetty, but they are not, in my opinion, adapted to the open coast of Madras, and after the experience we have had of the Madras pier, I imagine few will advocate their use.

7. Caissons may be constructed of timber or of iron, and of any shape, but in every case they require to be strongly put together in a dock, and after being filled with concrete or rubble masonry to the extent of their powers of floatation, have to be floated out, and with great labour and difficulty sunk in their proper positions, and then built on till their superstructure reaches the desired height. As a dock is indispensable for their construction, their use may be said to be out of the question at Madras, where such a convenience neither exists nor can be easily provided.

8. Stone alone, and in the form in which it comes from the quarry, seems to me the material which can be most fully relied on under the conditions which must regulate the construction of a break-water at Madras, and in this opinion I appear to be supported by Mr. deClosets, who has designed his work on the model of the Plymouth break-water, and who would make it consist wholly of blocks of rough stone, which, tumbled into the sea in the proposed direction of the break-water, would be allowed to assume the natural slopes which the waves would give them. This has been a well-established and successful way of forming break-waters, both in ancient and modern times, but engineers of the present day are not agreed upon its being the most advantageous method, as it entails a great expenditure of material, which might, it is supposed, be arranged to offer a firmer resistance to the waves by being disposed with a vertical face to the sea, instead of one inclined at a great angle. In deep water a wave has no progressive motion; it rises and falls in a vertical plane, and only acquires the character of translation when it reaches shallow water, or meets the long foreshore of a sloping break-water. For this reason a wave, on meeting with a vertical obstruction in deep water, receives no onward impulse, but merely rises and falls without violence; but the same wave on reaching the foreshore of the beach, and especially on encountering the long inclined plane of the surface of a break-water with a seaward slope, acquires a powerful forward motion, and rushes up that slope with such violence as sometimes, during storms, to tear up and carry with it stones of the largest size.

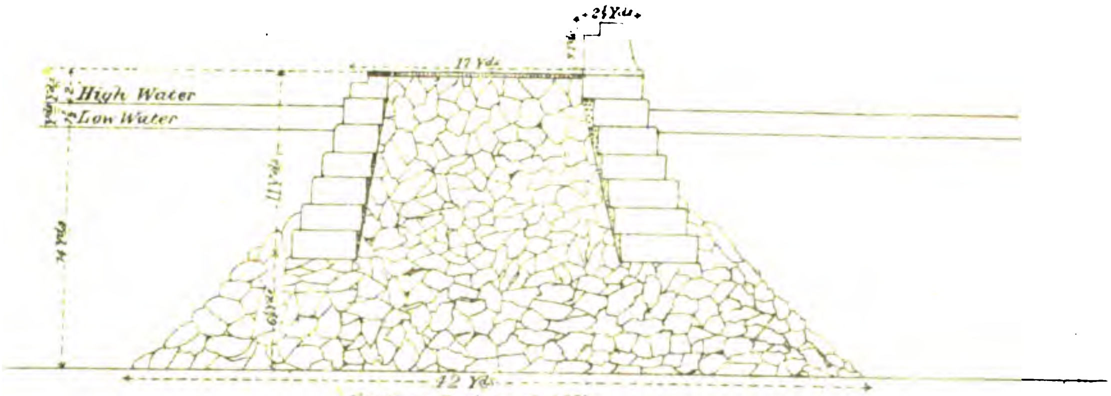
Theoretically, therefore, a break-water, in a depth of seven fathoms, to be able to resist the greatest force of the sea with the least risk of damage to itself, should be built with a perfectly upright face to seaward, thus—



Sectional area of masonry with stone casing 312⅔ Yds

Scale 33 Feet to an Inch.

9. This form, however, requires that each stone, of the facing course at least, should not only be of massive proportions, but should be dressed and fitted to its place with the greatest nicety, and be laid with the utmost care, and involves the erection of staging as well as the use of expensive diving and other machinery, and necessitates the employment of much skilled labour of special description. Though probably the most perfect, and requiring the minimum quantity of material, this system of construction is exceedingly expensive, and when adopted in a seaway or within the influence of strong currents, is attended with great difficulties and even dangers. It is not suited, therefore, to the circumstances which have to be dealt with at Madras, and I think a more simple, though less scientific, mode of construction must be there followed. But it is not necessary that the upright form in which a break-water is best capable of resisting the sea should extend to the full depth of the water in which it is placed. Waves have little or no force below the depth of the trough of the sea, and stones or other ponderous materials thrown into deep water assume natural slopes approaching an angle of 45° up to within a few feet of low water. An approved method of construction is, therefore, to throw down stones in the given direction of the break-water, and when the mass has been raised to nearly the height at which the waves would begin to act upon it, to build on it as a base an upright superstructure to the required height, as shown in the following section of a break-water so formed.

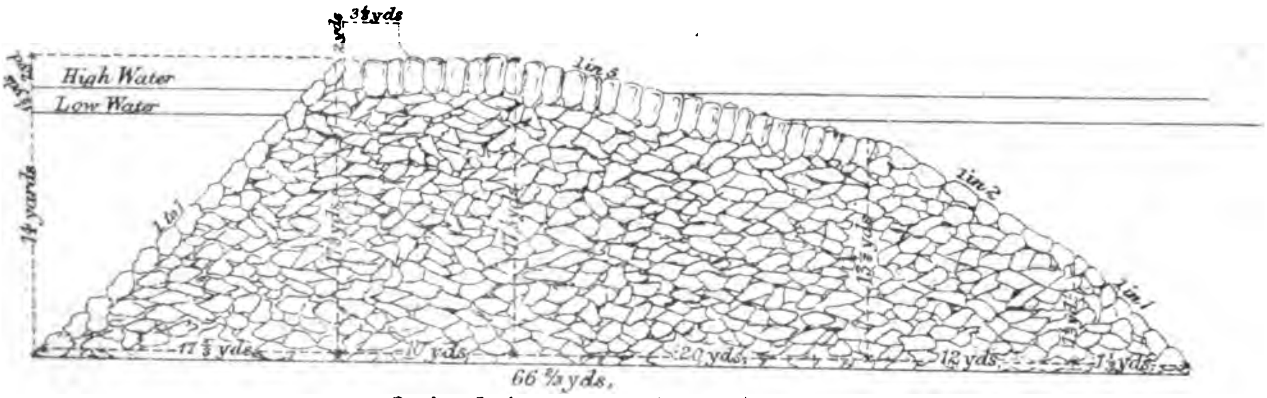


Sectional Area 661 Yds

Scale 33 Feet to an Inch

10. This method has been successfully adopted of late years at several places. The French have followed it in remodelling the break-water at Cherbourg, which, constructed originally of rough stone, or "pierre-perdue," is now being completed from low water upwards with a vertical section. Although not requiring carefully finished work to be done in deep water as in the vertical system, this method of construction cannot be resorted to without bringing into use in a modified degree the diving and other mechanical apparatus which it is so difficult to employ without a full command of skilled and trained labour, and it is, therefore, in my opinion equally unadapted to this country, where much skilled labour cannot possibly be advantageously employed. Neither of the two systems, then, by which a vertical break-water can be constructed being, in my judgment, applicable to Madras, I have no choice but to suggest the only other method in which I believe a substantial and durable work may

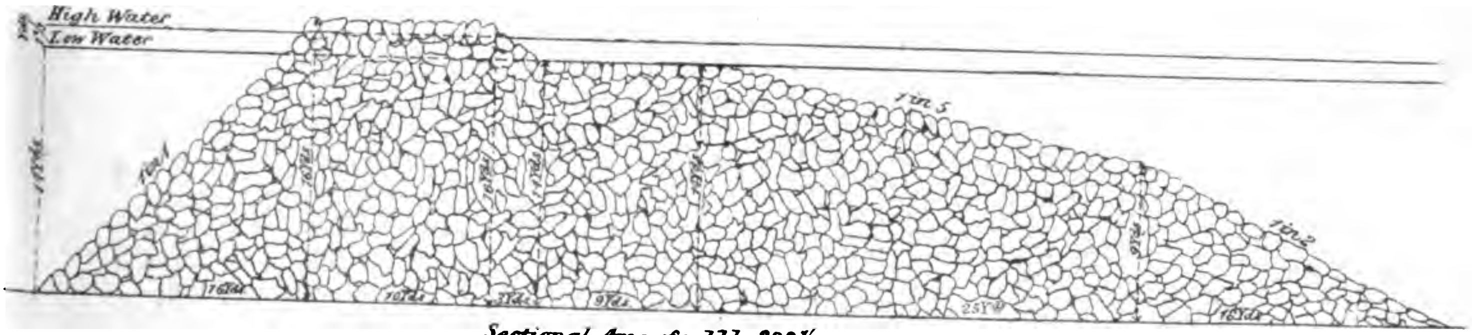
be constructed with the means either always available or readily procurable. That method is previously mentioned as similar to the one proposed by Mr. deClosets of throwing down blocks of stone just as they are got from the quarry, and allowing them to take the slopes which the waves will give them. These slopes are known from experience to be very moder-



Sectional Area of rubble 781⅛ yds. *Scale 33 Feet to an Inch*

13. It differs from Mr. deCloset's only in being suitable for a break-water in seven fathoms at low tide instead of at high tide, in having its sea slope carried down to low water instead of to 15 feet below that level, and in having its crest a few feet higher than Mr. deCloset's seems to think necessary.

14. This is Mr. deCloset's section—



Sectional Area of rubble 823⅓ yds

Scale 33 Feet to an Inch.

and it will be observed that there is little substantial difference between us. It is, no doubt, more in accordance with the experience obtained in other quarters of the world to continue the sea slope several feet below low water; but believing as I do that the sea at Madras cannot acquire the power to act with the disturbing force which it exerts in the more exposed situations where opportunities for noting its effects have been afforded, I am not of opinion that the seaward slope of a break-water here need be carried further than low water, and I think the material may be better disposed in giving elevation to the crest of the work, to enable it to afford better shelter and smoother water to the anchorage within it.

15. Adopting the rough stone, or "pierre-perdue" system, I would place the break-water directly opposite the town in seven fathoms at low water, and would give it a length of 2,000 yards. Seven fathoms will be found at a distance of about 1,200 yards from the shore, and directly parallel with it, and a break-water, 2,000 yards in length, will extend from opposite the Light-House to opposite the Railway Station, and will give cover to an anchorage in from three to seven fathoms of about 300 acres.

16. A reference to my section will show that I would make the top of the break-water 30 feet broad, and base it 6 feet above high water. This would give solidity, as well as great stability, and probably afford quite sufficient protection to the anchorage. If, however, the sea were found to wash over the crest to such an extent as inconveniently to disturb the anchorage, a sea wall in the position denoted by dotted lines might be added without difficulty. Constructed as I propose, the break-water, if stone in sufficiently large blocks be used, would probably occupy a base of 662¼ yards, and contain 781 cubic yards of stone for every running yard of its length, or 1,562,000 cubic yards in all. This is an enormous quantity of material, but it may perhaps be reduced by the judicious disposal of the large and small stone, the former being deposited on the outer slope and crest, and the latter all on the inner side, and as a core to the mass. The stone, as thrown in at random within the space marked out for the break-water, would probably stand at a slope of 45°, or one of base to one of height to near the level of the low water. From that point upwards the stones, in whatever manner they may be thrown down, will begin to assume for themselves under the action of the waves a long slope to seaward, and it will only then be necessary, as the work approaches the surface, to be careful to throw in all the largest stone on the outer side of the work, and all the smaller on the inner. The sea will arrange them of itself in the manner best adapted to resist its force, and the work may be brought gradually into shape by the judicious use of large or small stone as occasion may require. Ultimately, after the work has taken a permanent form, its surface may be finished off with a covering of large stones carefully packed on end.

17. I come now to the question of cost, and this is the most difficult part of the subject, for Madras is not fortunate in having quarries so situated as to allow of stone being shipped from them direct. The only spots in the neighbourhood from which stone can be had are the Red Hills, Palaveram, and Covelong. At the Red Hills laterite may be obtained, but scarcely in the quantities, and certainly not with the facility and rapidity which are essential. At Palaveram and Covelong excellent quarries of granite might be opened, but neither of these places, nor the Red Hills, has any direct water communication with the sea, and to transport stone from any of them in the large quantities that will be required, and in the large blocks which it is essential to use in the largest possible proportion, railways must be made, and means be provided for removing the difficulty of carrying ponderous masses across the surf. The surf is indeed *the* great difficulty, and no scheme for the construction of a work beyond it can be reliable, unless it provide clearly for overcoming or evading the obstruction which it offers. Palaveram, situated about 12 miles from the beach opposite the site of the proposed break-water, is the spot from whence, in what may be called the neighbourhood of Madras, stone may, in my opinion, be most easily procured, but for its delivery in large enough quantities and in sufficiently large blocks it will be necessary to make a tramway or railway to the nearest point on the coast, and there to construct a jetty into deep water beyond the surf. The distance from the Palaveram hill to the beach is about 6 miles, and the intermediate country being favourable, a railway, capable of being worked by locomotive power, might be laid with ease and at a moderate cost. The jetty would require to be a substantial structure, probably of screw piles carried out for at least 900 or 1,000 feet, to allow of barges approaching it with safety in all ordinary states of the weather. Shipped on barges, the stone, by the employment of steam-tugs, would be rapidly conveyed to its destination, and I see no reason to think that the break-water might not be successfully constructed with materials thus procured. There are, however, so many difficulties, delays from inclement weather, and other contingencies attending a shipment in a rough seaway of such ponderous blocks as the stone for a break-water ought to consist of, that it is worth while to consider whether stone of proper quality and in sufficient quantities may not be obtainable from some spot from whence, though not in the neighbour-

hood of Madras, water carriage may be available from the very verge of the quarries to the site of the break-water. I am acquainted with only one place answering this descriptton. It is Seetanagram, on the south bank of the Kistna, where the Southern Canal from the Bezoarah anicut takes off from that river, and, after traversing the Delta for about 40 miles, terminates in the tidal creek of Nizampatam, and, by means of it, has direct communication with the sea. At Seetanagram the canal skirts, for more than a third of a mile, a hill of 200 or 300 feet in height, from whence an inexhaustible supply may be obtained of stone which, quarried and carried all over the Delta already for the works constructed in connection with the Kistna anicut, can, I am inclined to believe, be delivered at Nizampatam, by reason of the cheapness of water carriage, at a cost not in excess of that at which stone is likely to be quarried and loaded anywhere near Madras, where the rock is either not well situated to be readily quarried in sufficient quantities, as at the Red Hills, or is of such hardness as to be with difficulty brokon up, as at Palaveram. Assuming this to be the case, then the expense and risks of transport by sea from Nizampatam, a distance of 195 miles, have to be set off against the cost of carriage by railway, and the expense, as well as the difficulties, delays, and dangers of the shipment of heavy masses over the surf, and their conveyance by barges from opposite Palaveram to Madras.

18. An estimate of the probable cost at which stone may be quarried and put on boats at Seetanagram can be pretty fairly arrived at by examining the records of operations on the construction of the Kistna anicut, and by making, on the one hand, due allowance for increased prices of labour, and on the other, for the use of more and better mechanical appliances than were available on that work. Stone was quarried and delivered on the anicut with a lead of fully half a mile from either side of the river, for rather less than 12 annas a cubic yard, and making the allowances I have mentioned, it may be safely assumed that it is not likely to cost more now than ₨1 on board a boat on the canal. Supposing a boat to carry 100 tons or 50 cubic yards, and, manned by ten men at ₨7 each per mensem, to make five rips, which is moderate work for one month, the charge for carriage to Nizampatam will be $\frac{70}{50 \times 5}$=·28 of a rupee, or only 4½ annas per cubic yard. A cubic yard of stone may, therefore, be estimated to cost not more than ₨1-4-6 delivered at Nizampatam, and I feel pretty confident that it can nowhere near Madras be even quarried in quantity and in blocks of size less than that sum. Transport by sea is indeed so cheap that it is not a matter of much importance whether it be over a distance of 200 miles from Nizampatam or ten from opposite Palaveram. In either case a large number of barges and steam-tugs must be engaged, and I cannot but think that the longer distance will be more than compensated for by the avoidance of all difficulty in crossing the surf. I have spoken of the probable price of stone as delivered at Nizampatam, but it will not be necessary for any transhipment to be made there. The canal is navigable for boats drawing four feet of water, and the locks on it being 150 feet long by 20 feet wide, it will be easy to build barges which, taking the stone on board at Seetanagram, will proceed with it direct to Madras, being towed by steam-tugs from Nizampatam. These barges, if made 90 feet in length by 18 feet in breadth and perfectly flat bottomed, would carry 100 tons or 50 cubic yards with three and-a-half feet draft of water. They would of course be unable to sail, and would have to be towed both ways on the sea portion of their voyage by steam-tugs, each of which, say of 40-horse power, would easily make a trip in five days with six such barges. Taking the expense of such a steam-tug at ₨120 per diem, including the cost of five tons of coal, and that of each boat at ₨2½, the cost of transport per cubic yard from Nizampatam to the site of the break-water, supposing each boat to carry, as I have said 50 cubic yards, would be $\frac{120+15\frac{1}{2}\times 5}{50+6}$= ₨2-4-0. Adding this to the price of Seetanagram stone brought as far as Nizampatam we have ₨3-8-6 as the cost of stone from that source of supply at the break-water. This is, however, exclusive of the value of the extensive plant that will be required in the shape not only of barges and steam-tugs, but of cranes, temporary tramways, wagons, and quarry apparatus of all kinds, and does not provide for the cost of superintendence, which will be a heavy item, owing to the extended nature of operations and to the length of time they will occupy. Making due allowance for all these, the cost of a break-water, according to the section I would adopt, may be approximately estimated thus :—

	₨
1,562,000 cubic yards of stone, at say ₨3-8-6	55,15,813
200 barges, at ₨4,000	8,00,000
15 Steam-tugs, at ₨50,000	7,50,000
Cranes and other plant	2,00,000
Superintendence, at ₨1,00,000 per annum for twelve years . .	12,00,000
TOTAL .	84,65,813

19. If Seetanagram be considered too distant, Palaveram is, I believe, the only other place from which stone can be procured. Assuming that it can be obtained from thence in the manner I have indicated, I estimate its cost, delivered at the break-water, per cubic yard to be—

	R	a.	p.
Quarrying, the stone being hard	2	0	0
Loading	0	2	0
Carriage by rail to boat	0	8	0
Loading on boats	0	4	0
Cost of conveyance by barges towed by steam-tugs at one trip in one and-a-half day	0	7	3
	3	5	3

exclusive of the cost of railway, pier, steam-tugs, quarry plant, and superintendence. With these items the approximate estimate will be—

	R
1,562,000 cubic yards, at R 3-5-3	51.98.531
Railway, seven miles, including sidings, &c.	5,00,000
Shipping pier	5,00,000
50 barges, at R 4,000	2,00,000
4 steam-tugs, at R 50,000	2,00,000
Superintendence for twelve years	12,00,000
	79,98,531

showing a difference of 4½ lakhs of rupees in favour of stone from Palaveram, supposing the Palaveram stone can be quarried for R2 per cubic yard, and that steam is not used as the motive power between Seetanagram and Nizampatam, in the way in which it may be advantageously applied to the traction of the barges by means of a chain laid along the bed of the canal in the manner adopted on the River Seine. My estimates give, I think, a sufficiently near approximation to the relative cost of stone from the two places, but of course neither would be selected without further full inquiry.

20. It is unnecessary to enter into any details of the manner in which the work of constructing the break-water should be conducted, as these will be best arranged by those who may have their direction; but I may say that, though the work will probably not be completed within less than twelve years, it would be more or less a defence to the anchorage from the first, and, if begun at the centre and carried on north and south simultaneously, it would, after a year or two, afford ample protection to a very considerable area for anchorage.

21. But this is not the only use which may be made of a break-water in an advanced position off the coast. As things now are, the whole line of the beach, including the Fort, Black Town, the Custom-House, and many of the principal public and private buildings and establishments of the Presidency, is exposed to aggression by any armed vessels that may make their appearance on the coast. A single ship of war, carrying the long-range ordnance which is now in use, could, with perfect impunity to itself, lay the greater part of Black Town and those buildings and establishments in ruin, or drive the shipping in the roads on shore. Batteries on the beach will have no power to prevent this, but if planted on a break-water, 1,200 yards to seaward as they would then be, and crossing fire on the one hand with the guns in the Fort, and on the other with those of Clive's Battery, they would make it impossible for any vessel to approach.

22. Such batteries might be built at each end of the break-water by a small enlargement of the work to form a base for their support, as shown in the accompanying plan, which illustrates how a battery may be formed with its magazines, store-rooms, &c., but is not intended to represent the description of work which should be built, as it is probable that it will be advisable to adopt the system of iron defences which it is now so necessary to employ to resist the power of modern artillery.

23. I have not noticed the abortive attempt that was made thirty-two years ago to form a break-water at Madras, because the break-water then contemplated was totally different from that which is now proposed, and was commenced with means so ridiculously disproportioned to the nature of the work to be done as to render the failure of the undertaking certain from the first.

24. With respect to the financial aspect of the undertaking, the Chamber of Commerce seems to be of opinion that one rupee per ton on the shipping frequenting the port would yield a handsome return. The latest statement I have been able to obtain of the trade of Madras is that of 1865-66. From that statement it would appear that the aggregate tonnage of all the shipping, whether steamers, square-rigged vessels, or native craft, that enter the port during the year was 3,53,015. One rupee a ton upon this would yield a little less than 4 per cent.

supposing the break-water to be completed for 85 lakhs of rupees, and would not quite suffice to pay the interest at which this sum could be raised. One rupee a ton seems, however, a very light charge to impose in return for the security a break-water would confer on the shipping, and for the facilities it would afford to the landing and shipping of cargoes, as well as for the important saving of time that it would enable consignees and shippers to effect. We have heard much of late of the great delay experienced in landing and shipping goods, and of the exorbitant prices voluntarily paid for the hire of boats, and it is surely not looking for too much to expect merchants to be glad to get rid of the uncertainties and difficulties which now beset communication between the shore and the shipping at a price somewhat more commensurate with the advantages obtained. A charge on every ton of goods landed or shipped seems to be a far more reasonable method of raising the requisite revenue, and I think one rupee per ton each way should not be found a burdensome impost. This would double the returns calculated upon by the Chamber of Commerce, and, yielding about 7 lakhs of rupees, would be sufficient to relieve the State from the burden of interest which it would be necessary to incur for the construction of the break-water, and leave a margin for its maintenance.

25. As regards the question of the agency by which a break-water should be constructed, it may be observed that experience has not shown that any advantage is obtained by the adoption of the system of carrying out large works in India by means of private enterprise, combined with Government supervision. So long as Government can borrow whatever funds it may require at the same rate of interest which it would have to offer as a guarantee to a private Company to undertake the work, it is not easy to see why the Government should transfer to any private parties whatever the complete control over the expenditure, which it can exercise in an efficacious manner only when it keeps the outlay in its own hands. A break-water is essentially a national work which, in my opinion, should be taken up and executed by the State itself from the ordinary revenues of the country, on which its cost would not press very heavily, since the expenditure, though in the aggregate large, would be spread over a number of years, and might be met by a comparatively moderate annual grant.

CHARLES A. ORR, *Colonel, R.E.*

September 4th, 1868.

Report by Mr. G. Robertson on the proposed Madras Harbour, 1871.

I have carefully perused the papers in connection with a proposed ship harbour at Madras, and have examined the various designs which have been submitted by engineers and others.

The Report of the Committee appointed by Government in 1868 is a very able document, and contains much valuable, and in some points exhaustive, information. It was compiled by eminent engineers of the Public Works Department, in conjuntion with officers of the Railway Company, and the Master-Attendant.

The President of the Committee, Colonel Carpendale, did not concur with his colleagues in much of the Report, and recorded his opinions separately. His opinion appears to me to be well worthy of grave consideration, though I do not concur with him in the result he arrived at, in preferring a close harbour, which would probably require a break-water in addition, to keep out the swell.

The designs I have examined are those of Mr. DeCloset and Colonel Orr, Messrs. Chisholm, Doyle, Fraser, Rymer Jones, Wells, and Captain Heathorn, Parkes, and Captain Taylor. The Madras Chamber of Commerce also supplied me with a copy of a scheme by Mr. DeCloset, for constructing docks on the island.

I fully concur with the remarks of the Committee, against any attempt to form a break-water, or piers of any kind, of a complicated structure, in a situation like Madras. Neither do I think that anything of the nature of a boat harbour will succeed, until the shore is protected from the action of the surf.

After a full consideration of the whole subject I have come to a decided opinion, which is—that before any works can be safely commenced, more must be known regarding the most important points in connection, either with a close harbour or a break-water,—*viz.*, the currents close in shore, and the amount of sand in motion at the coast line. The whole success of any scheme depends on this knowledge. The littoral currents, and the quantity of sand in motion, have been freely spoken of, and taken for granted by the Committee, and by others; yet what real evidence is there about them? The internal evidence in the Committee's Report is conflicting. The usual question put to a witness commences as follows:—

"The European diver has informed the Committee that the loose bed of sand on the beach does not extend beyond the six-fathom line, and that there is *no current at the bed of the sea at seven fathoms.* Assuming this to be the case, and as we know from soundings taken

along the pier for five years, from which there appears a variation in the depth of sand at the pier head, of five feet at different seasons of the year, *there is reason to conclude that the sand is chiefly moved out to sea and into shore, and not carried much north and south.* What is your opinion of a harbour?" &c., &c.

The italics are mine.

Let this question of the Committee be compared with a portion of their remarks, in paragraph 13 of the Report on Mr. Fraser's design—

"We cannot agree with Mr. Fraser, either that the quantity of sand which is carried along the shore with the littoral currents is of so limited an amount as to render it capable of being controlled by artificial works, or that the effect of a series of groynes would in any way differ from that of the small groynes which have already been thrown out from the beach at Madras, which has practically resulted in the extension of the beach to near the end of the groynes. The actual quantity of sand moved along the shore is certainly unknown, but if the construction of groynes leads to the formation of a new sea beach, in advance of the original one, and precisely similar to it, the inference is, that either the sand which has been heaped up was derived from material *brought to the spot by littoral currents*, or that, if it were thrown up by the surf, the quantity thus obtained *from the bed of the sea was replaced by an equal quantity brought from a distance.* We consider that there is strong reason to conclude that if a beach is extended a hundred yards by means of groynes, it might be extended a hundred yards further by continuing the process, and in each case a new line of beach being formed precisely similar to the original beach, there would appear to be nothing to prevent the shore being extended to any amount that might be desired."

I might quote other passages in the Report, such as those in paragraph 14, on the design by Mr. Rymer Jones, but the above is sufficient.

The Committee, in their question to the witnesses, say, there is reason to conclude that the sand is chiefly moved out to sea and into shore, and not carried much north and south; while in their Report they decide against a close harbour, on account of the quantity of sand brought by the littoral currents running parallel with the shore.

There is hardly a scrap of reliable evidence about these littoral currents. Mr. Shilleto, the European diver, says, "no current at bed of sea at seven and eight fathoms; if there was, he could distinguish it."

Captain Dickinson, of the steamer *Cashmere,* states, as positive information, that the velocity of the littoral currents, particularly in the monsoons, and from 1,200 yards off the shore to 600 yards off the shore, is seldom more than 1 mile an hour.

Captain Lewis gives the currents in the N.E. monsoon as the strongest, and at a mile from shore estimates the velocity at from three-quarters to 1 mile per hour. Neither of the officers states whether he had actually measured the currents. Assuming there is a current of 1 mile an hour at 1,200 yards from shore, in seven fathoms, it is essential to know what are the currents nearer the coast line, for the diver says the bed of loose sand does not extend further out than six fathoms. On this point no information has been laid before me. The probability is, that the current of 1 mile an hour is much diminished near shore by friction on the bottom.

Any tendency to travel in the bed of loose sand which fringes the coast, must be due to whatever velocity these littoral currents have, combined with that oblique action of the surf, caused by the ocean currents, which I have alluded to in my Report on Cochin. These are the two agents at work in moving the sand. If the velocity of the littoral currents is not sufficient of itself to carry the sand along the coast to the north, or to the south, then the withdrawal of the other agent, the surf, would cause the sand to be deposited at any place where the littoral currents alone are at work.

In short, if there is such an immense quantity of sand in motion on the shore at Madras as to be beyond the power of control by groynes, or otherwise,—such a quantity as to render probable, as the Committee think, the formation of a fresh beach extending out to the very end of long piers,—then my opinion is, that even a break-water will not succeed. It would still the surf, and thus remove one of the two agents which move the sand—and I do not think it will have any effect in strengthening the currents. The consequence would be, that the sand would accumulate behind the break-water, and fill up the sheltered spot, unless the littoral current is strong enough to sweep past, with the sand in suspension. The more successful the break-water in creating quiet water behind it, the more certain would be the destruction of the scheme from silting.

The Committee, to a small extent, have some idea of this objection to a break-water, for in paragraph 28 they allow that "there will be a certain extension of the foreshore, which would adopt a more abrupt slope than it has at present, but that the capacity available for ship-

ping, and the facility for the communication to and from the shore, would thereby be increased, rather than diminished."

Who is to insure that the foreshore will stop at this "abrupt slope," and not extend out till it joins the break-water? I am certain it would—if there is enough sand in motion to render probable the growth of the beach out to the end of the piers of an enclosed harbour.

It must be remembered that at Madras there is no great river near at hand, pouring down torrents of silt, and furnishing fresh supplies for the littoral currents to carry off.

I make these remarks, not because I have come to a different conclusion from the Committee, but to show the necessity there is for some more information as to the littoral currents, and the quantity of sand in motion on the coast, before coming to the conclusion that a break-water is feasible at Madras.

With this proviso, therefore, that the necessary information is incomplete, I will state my opinion as to the formation of a port at Madras, as the Government of India have asked me to give it.

In paragraph 40 the Committee say, " Before closing our Report, we beg leave to submit a few general remarks in support of the conclusion at which we have arrived. If it were possible to construct an enclosed harbour, which should be secure from the danger of shoaling up, we should not hesitate to recommend it in preference to a break-water. It would be greatly superior in every respect. The piers would be constructed from the shore, and at far less expense, in proportion to the material used, than the break-water; the accommodation for shipping, and the facilities for landing and shipping cargo, would be greatly superior to those afforded by an open harbour. But we consider that all these advantages would be rendered nugatory by the shoaling of the harbour, which would certainly result from the construction of any solid piers or groynes from the shore, and we are strongly of opinion that a break-water is the only work from which any real improvement is to be hoped. It will not afford a perfect harbour—no break-water does—but it will effect an immense improvement on the present exposed state of the roads."

I have come to the same conclusion as the Committee, but from entirely different reasons. I have shown that there *may* be as much, if not more, danger from shoaling in the case of a break-water, as of an enclosed harbour; but, taking all the circumstances connected with Madras into consideration, a break-water appears to me to be preferable to an enclosed harbour. For an equal sum of money it will give much more *deep* water shelter than a harbour; it will create a considerable length of sufficiently smooth water at the coast line to enable boats to land, or to come to jetties; and vessels can enter and quit more easily from behind a break-water than through the one entrance of a harbour. A harbour such as that designed by Mr. DeCloset, in connection with the docks on the island, would admit so great a swell that vessels would be dashed to pieces in attempting to enter the docks.

The break-water should be in at least seven fathoms water, and be at least 2,000 yards in length, as proposed by the Committee. I should prefer to put it farther out, so as to give more deep water shelter; but the increased section, and necessarily greater length to shelter the same extent of beach, would make the cost more than the financial view of the question might warrant. The break-water should be perfectly straight, and have no splayed ends, so as to give the greatest amount of shelter with a given length of break-water.

The slope of the inner face of the section of the break-water proposed by Colonel Orr is too steep; ordinary rubble would hardly stand, under the action of the sea, at a slope of 1 to 1 from the top to the bottom.

The following are the slopes which the unpitched rubble deposit in the outer break-water at Portland has finally assumed after years of exposure to the action of the sea:—the width at the top being 30 feet; the height 5 feet above high water of ordinary spring tides; the rise of tide 7 feet 6 inches, and the depth of water about 10 fathoms. The sea slope is 6 to 1 down to low water of ordinary spring tides, then 5 to 1 for a depth of 12 feet, 1¾ to 1 from that to 22 feet, and the remainder 1½ to 1. The inner face has a slope 2 to 1 from the top to low water, and from there to the bottom 1½ to 1.

In estimating the cost of a break-water for Madras I have taken these slopes, but have assumed the top at 6 feet above high water, which is the height of the modified form for the pier at Wick, and of the break-water in course of construction at Port Erin. The water should be allowed to come freely over the break-water, and not be checked by a parapet of any kind.

In estimating the cost of their breakwater, the Committee have made no deduction for interstices between the stones, for in paragraph 42 they say, " We recognise the necessity of providing a large surplus to make good wastage, by the dispersion of some of the smaller material during the progress of the work, or before it may become duly consolidated, as well as

by the subsidence of the stone in the bed of the sea." This is far too great an allowance, and has *unnecessarily* added, at least, 17 lakhs of rupees to their estimate. When I was on the works of the Holyhead break-water, the usual allowance in calculations for the deposit was 20 cubic feet to the ton. This gives the interstices as more than one-fourth of the bulk as deposited. One-fifth may safely be taken off the quantity of stone calculated by the Committee, and enough margin be left for the wastage alluded to. There is, in point of fact, very little, if any, waste; because the section is calculated at the full size the deposit is supposed to become under the action of the sea. There is a little waste in quarrying, because very small stuff should not be allowed in the deposit; but that would be left in a spoil-heap at the quarry and not brought by railway to Madras—and it is the railway freight which makes the construction of a break-water at Madras so very costly. I think more inquiry into the best source of stone supply should be made, as 51 miles is a long distance to bring a large daily supply of material. The railway freight of stone, if brought from Trittany, would amount to the cost of a very respectable length of special line to a quarry nearer at hand. On this head, however, the Committee remark that "the whole cost of carriage will, by the employment of the Madras Railway as the means of transporting the material, be in one sense returned to Government, and go to reduce, by the amount of profit on the undertaking, the Government guarantee for interest." According to this ingenious view the distance of the proposed quarries is not a matter of much importance.

The real difficulty in constructing a break-water, as proposed by the Committee, is the water carriage from the shore to the site of the work. It is proposed to put up a pier 300 yards in length, for the purpose of facilitating the delivery of the stone into boats, thence to be towed by the aid of steam-tugs to the site of the work, and there deposited by cranes. It is calculated that 2,000 tons of stone per diem may be deposited in this way for 235 days in the year, and that the whole stone may therefore be deposited in eight years after the completion of the pier. My impression is, that a very much longer time will be required than eight years. In a swell like that at Madras, the difficulty of shipping and depositing stones, some of them many tons in weight, can hardly be over-estimated.

The only way to construct the break-water, *within a reasonable time, and to be independent of the weather*, is to run a pier on screw piles, and carrying two lines of rails, *out to the site of the works*. This may apparently add a little to the estimate; but, in practice, it will be the most economical way in the end. The break-water may be made either by an end tip, or from a staging. I would advise the latter, which has been used in almost all large sea-works, ever since it was first adopted by the late Mr. Rendel at Holyhead and Portland. In this country the cost of a staging comes to about 3*d.* per ton on the stone deposited. At Madras I calculate a staging will cost 4 annas per ton of deposit. This is not all extra or lost money; for the ease and certainty with which the stone can be deposited, independent of the weather, and the nicety with which any part of the work can be fed with material, as the sea pulls it out, are well worth the expense of the staging.

I have had an opportunity of trying all three ways of executing structures of this kind in the sea, in the same work. In the construction of the reclamation embankment for the Prince of Wales' Dock at Leith, it was convenient to do half the work from a staging, and half by an end tip; both methods being supplemented by stones brought by lighters and boats. The experience gained, in those three ways of executing the same work, was so much in favour of the staging, that, when tenders were invited for a much longer bulwark to enclose the site for the Albert Dock, a staging was made imperative in the contract.

By using a staging, more than a million of tons has been deposited in one work in a year, and I have known 5,220 tons of stone deposited in one day. This, however, requires very perfect arrangements, especially at the quarries, where the preparations for the large blasts have to be commenced many weeks before the stone is required.

After the construction of the break-water, the greater part of the pier may be taken up and the materials used to widen the remainder for traffic purposes. The pier will be, for a time, somewhat in the way of ships using the anchorage, but not more so than the piers of an enclosed harbour. Steamers can easily go round it, and a tug should be provided to assist sailing vessels during adverse winds.

The staging from which the stone is deposited should be made of double timbers, fished together as at Holyhead and other places, and should have on it five lines of rails.

I have made an estimate of the cost of a break-water constructed in this manner, including a pier 1,200 yards long to connect the work with the land, and including also the necessary superintendence and plant.

I estimate the whole at R1,14,00,000. Allowing 15 per cent. for contingencies, brings the amount up to R1,31,10,000—or rather under one and a third millions sterling.

The estimate made by the Committee was R1,06,20,325, but they recommended Government to be prepared for the probability of their estimate being exceeded by nearly as much as 25 per cent. By connecting the work with the shore, and by depositing the stone from a staging, the rate of execution is so much more reduced to a certainty that I have only allowed 15 per cent. for contingencies.

With good arrangements the break-water may be constructed very easily in six years after the completion of the pier.

The question of fortifying the break-water is one more for a military than a civil engineer to consider. It has always, however, appeared to me that an iron-clad, which can act on the offensive as well as the defensive, is the most suitable fortress for a commercial harbour.

I may mention, in connection with the subject of a break-water at Madras, that on the 1st of July I received, by order of the Secretary of State for India, a letter (with enclosures) which had been sent to His Grace by Mr. R. Saunders, relative to his "patent floating break-water." This was sent for my information, and for any observations which I might have to make thereon.

I examined Mr. Saunders' designs, and found them possessed of several features of merit. The peculiar construction of his floating pontoons would have the undoubted effect of very much destroying the waves of oscillation caused by local winds, and of giving considerable shelter behind them. But they, in common with all known designs of a floating nature, would have little effect in counteracting the ground swell or rollers which come in after a storm at sea, and which is the worst form of wave a break-water has to resist. In small harbours, where the reductive power on the waves is not great, or where dock-gates have to be protected from a ground swell, such as those of West Hartlepool Dock, it is found necessary to use booms, brought up from the bottom in grooves of masonry. Nothing floating will turn the swell.

Besides this objection—and it is the principal one—to a floating break-water, there is another, which I may state in the words of Mr. Scott Russel, at a meeting of the Institution of Civil Engineers: "The lee side of the 'Great Eastern,' when lying at Holyhead, afforded excellent anchorage for small vessels in light breezes. But when the roller, the one great wave of translation, came, the anchors snapped at once, showing the danger which would have been incurred had she been moored broadside to the roller instead of offering to it the small resistance of her fine bow. No known force could effectually secure a large floating break-water broadside on to a heavy ground swell. It would move horizontally with the wave of translation, which would propagate itself along the bottom, just the same as if the break-water was not there."

The difficulty of mooring a floating pontoon broadside on to a swell is one for experiment and one which I think might be overcome; but the first objection is, in my opinion, fatal to any floating structure, however skilfully designed for the reduction of waves of oscillation.

The papers sent to me regarding Mr. Saunders' break-water state that Company is being formed for the working of the patent. If the Company would construct three pontoons, and moor them at an exposed point of the coast, they would do more, if successful, towards the introduction of floating break-waters than any number of favourable opinions can effect. As yet the question has been a matter of opinion, and not of experiment. I, for one, will rejoice if my opinion turns out to be wrong; for a floating break-water, moored off the sandy shores of India, or placed so as to shelter the mouth of a river, and prevent the surf from throwing up a bar, is a desideratum much to be wished for, but, I fear, unattainable.

It does not come within my duty to enlarge upon the disadvantages under which ships labour in coming to Madras at present. The merchants of that place are fully alive to the danger to which they are exposed, of gradually losing the greater part of the trade, which, in spite of such disadvantages, has hitherto been attracted to Madras.

BLACKWOOD'S HARBOUR.

Before leaving Madras I received the following letter from Colonel Orr:—

P. W. Dept.,

Fort St. George, *28th April 1871.*

Sir,—In continuation of my letter of the 23rd February 1871, I am directed to forward the accompanying papers, from which you will observe that the Government of India having called for a Report on a proposal to construct a safe anchorage on the Coromandel Coast, as a substitute for the dangerous roadstead at Madras, by improving the means of shelter to be formed at the spot known as Blackwood's Harbour, they were informed that the subject would

be referred to you on your arrival at this Presidency. I am accordingly to request you will be good enough, in the course of your examination of the port of Madras, to take the opportunity of favouring the Government with your opinion of its capabilities, and of the expediency of adopting any measures for its improvement.

I have the honour to be,

SIR,

Your most obedient Servant,

(Sd.) CHARLES A. ORR, *Colonel, R.E.,*
Secy. to Govt., P.W.D.

In accordance with this request I have carefully perused the Reports which were sent to me about Blackwood's Harbour, and have examined the chart of it which was made by Captain W. Maxfield in 1821.

The piece of water which lies between Armogham shoal and the land, called "Blackwood's Harbour," is, to a considerable extent, protected from the heavy ground swell of the ocean. No part of the shoal, however, has less water upon it than 2¼ fathoms, according to the plan referred to, or 1¾ fathoms according to the chart published by the Hydrographic Office in 1851. Over the northern portion of the shoal a ship can sail. While, therefore, a very considerable protection is given to the anchorage by the Armogham shoal, a break-water would require to be constructed on the highest part, called the "Reef," before Blackwood's Harbour could be used extensively, either as a commercial harbour or a harbour of refuge. This is acknowledged by Major-General Anstruther, Major Cotton, Sir Frederick Arrow, and others, who have written on the subject.

Major-General Anstruther has proposed to effect this by erecting pyramids of stone along the crest of the sand-bank at intervals, expecting these heaps of stone would, in time, cause the formation of spits of sand on the north side, "thus gaining, at little cost, a natural break-water of sand."

Major Cotton agrees with this view, but differs as to the exact shape of the expected sand-bank.

The nearest point of Armogham shoal is fully a mile distant from land, in 5 fathoms water: and the average distance of the shoal is 4 miles, with 5, 6, and even 7 fathoms of water between it and the shore. What evidence is there, of any kind, that there is such a body of sand in suspension in the sea at 4 miles from land, that a break-water of sand would be likely to be formed by piles of stone deposited on the shoal? My opinion is, that such a result, if it ever did come to pass, would require a geological period of time. It is quite a different case from the silting feared by the Madras Break-water Committee, when they reported against the piers of an enclosed harbour at that place. There they had some grounds for believing that a great deposit of sand would take place, because the piers would have to be projected from the bed of loose sand which fringes the coast, and in which groynes have already been placed, with the effect of causing a certain amount of accumulation. But there is no evidence whatever to support the probability of the creation of a deposit of sand at Armogham.

It does not even follow that the shoal itself was ever created by deposit. It is called a "shoal," because the bed of the sea at that place rises above the level of the vicinity, and shallows the water. But it *might* be that Poondy Point once extended farther out, and that the Armogham shoal is the result of an encroachment of the sea; or, *if* formed by deposit, ages may have elapsed during its formation. In short, I think it extremely improbable that there is so much sand in suspension, in 7 fathoms water, and at a distance of 4 miles from land, on a shore so far from large rivers that a break-water would be formed, in a reasonable time, by Major-General Anstruther's plan.

If a break-water is to be made at Armogham, it must be constructed in the ordinary way. In 2½ 3 fathoms, there would be no difficulty in doing this, except as regards the loading and depositing, by barges in a sea-way. That difficulty only affects the time and cost of construction. The section would be, of course, very much smaller than that required for Madras; but the length of the break-water to protect a given length of beach from surf would require to be much greater than at Madras. The proposed break-water at the latter place is only 1,200 yards from shore; at Blackwood's Harbour it would be 3 miles, or more according to the part of the shoal selected for its site. Indeed, the break-water would require to be very long indeed, to still completely the surf on shore, though a shorter length would answer all the requisites for a harbour of refuge.

In the evidence laid before me there is some difference of opinion about the surf on the coast behind Armogham shoal. Captain Maxfield, in his Report, says that the surf is at no time dangerous, and that he daily landed there in ship's boats, from the 22nd of May to the 15th of June, three or four days only excepted. This is, to a certain extent, confirmed by the Report of Captain Cowles in 1823.

Mr. Grant the Master-Attendant at Madras, in 1823, on the other hand, affirms in his Report that "it is true the shelter afforded by the Armogham shoal breaks the force of the surf, in some degree, upon the beach within its verge; but, whether from the depth of water on some parts of the shoal, or an undulation caused by re-action, there is at all times, in many places on the shore, within this verge, quite as much surf as on the beach at Madras, although it breaks but once."

I have already said that a break-water can be easily constructed on the Armogham shoal. It would shelter completely a fine stretch of water for purposes of refuge; and, if made of great length, would also shelter the beach for trade purposes.

But if a large sum of money is to be spent in constructing a break-water in this neighbourhood, why not spend it at Madras, where it is more immediately wanted, and where trade is already established?

Madras cannot be shifted to the vicinity of Armogham shoal; and ships will always come to the centre of business, in preference to landing their cargoes, however easily, on an inhospitable coast 45 miles away, even if connected with the capital by a canal or railway.

The advisability of spending a large sum of money at Blackwood's Harbour depends, therefore, chiefly upon the necessity there is for a harbour of refuge. Would the shipping of Madras ever take refuge at Armogham? It is not often that they are forced to run from Madras roads; and it must be remembered that during the worst time of the year for heavy gales on that coast, both winds and currents are against ships leaving Madras for Blackwood's Harbour.

It is most desirable to have a safe anchorage on such a coast as the Coromandel, but it appears to me that it would be wiser and more remunerative to lay out one and a third, or even two, millions sterling, in protecting the present anchorage at Madras, than to spend one million in a break-water on the Armogham shoal. It is as much a common-sense as an engineering question.

I have no very reliable data for estimating the cost of a break-water on Armogham shoal; but I think that for about one million sterling, a considerable portion of Blackwood's Harbour may be protected, and made a safe and excellent anchorage.

Note by William Parkes, Esq., M.I.C.E., on the formation of a Harbour at Madras, 1872.

The exposed state of the Madras anchorage has long been felt as an evil for which a remedy ought to be provided, and an impetus has been given to the question by the accounts of the loss of life and property in the late severe cyclone.

2. Some months previous to that disaster, Mr. Robertson, Harbour Engineer for India, had visited the place, and after informing himself of the local circumstances and requirements, has made a report which contains a suggestion for remedying, or at least mitigating, the evil, and an estimate of the cost of the work he proposes.

3. I should not have considered it right to have put myself forward in this matter if I had not been convinced that Mr. Robertson's report would have the effect of retarding, rather than advancing, the object in view by suggesting difficulties which I believe to be unreal.

4. Mr. Robertson's estimate for the work he recommends is, I am confident, fully double what it need cost, and the scheme itself must, I think, appear to the majority of persons who look at it from a practical point of view so incomplete, that it would, if carried out, involve the construction of supplementary works on a scale not much less than that of the original one, before any substantial advantage could be obtained.

5. I should fear, therefore, that the only deduction likely to be drawn from Mr. Robertson's report is, that the evil is practically irremediable on account of the enormous cost of the remedy. The real facts of the case warrant no such conclusion.

6. I am aware that my authority to speak on the subject will be questioned on the ground that I have not personally visited the place, and I admit that this fact renders it necessary for me to be careful not to overstep those limits within which conclusions based on data within my knowledge cannot be materially modified by such local considerations as can be properly weighed only on the spot.

7. I think, however, that such limits in this case are unusually wide. The physical conditions are remarkably simple, and I have a great advantage in the fact that Mr. Robertson has himself by his local examination cleared the ground and excluded from the question complications which can only be eliminated by such a professional enquiry. On the ground so prepared for me by Mr. Robertson, I formed a strong impression as to the right course to be adopted, but I should not have felt justified in pledging myself to it as a positive recommendation if I had not had the further advantage of submitting my first crude ideas to Captain A. D. Taylor, one of the most experienced surveying officers of the late Indian Navy, and an authority second to none on the hydrography of this part of the coast of India. Captain Taylor's information has served to confirm my own previous impression, and I am authorised by him to say that he entirely concurs in the recommendations which follow. Indeed, in the form in which I am about to present them, they may be considered as made jointly by Captain Taylor and myself, though, as the subjects on which we are individually qualified to speak are different, we could not so conveniently embody the expression of our views in a joint statement. He has, however, favoured me with a statement of his opinion on the nautical part of the question, which will be found appended.

8. The recommendation put forward by Mr. Robertson is for a straight break-water, 2,000 yards long, 1,200 yards from, and parallel to, the shore, in a depth of 7 fathoms. (The rise and fall of tide is so small as to be no element in the question. It is given as 3½ feet at springs in the Admiralty Tide Tables, but Captain Taylor says this is a very extreme range.) Such a break-water Mr. Robertson estimates at £1,140,000, or, allowing 15 per cent. for contingencies, at £1,311,000. As he gives the grounds of his estimate, I have been enabled to form an opinion upon it, and my conclusion is that it is very unnecessarily high.

9. Mr. Robertson takes as his model the Portland break-water, which is a mere mound of rubble-stone which the sea has been allowed to wash down till the slopes have become permanent. Taking a mound of such a form and dimensions, calculating the quantity of stone required for its formation, and dividing this quantity into the estimated cost, I find that Mr. Robertson has assumed that the stone will cost (including staging, pier from shore, and, I presume, circular heads of masonry, but exclusive of the 15 per cent.) about R8 per ton.

10. Now, I readily admit that the Portland break-water is a noble and successful work, and that it might be a proper model for another break-water, if such had to be constructed under similar conditions. But I unhesitatingly deny that it is a proper model to adopt under conditions so different as are those of Madras. The stone at Portland cost, I believe, about R2 per ton, instead of R8, as estimated at Madras. Do the resources of engineering science suggest no means of modifying the form of structure, so that the total cost may not also be quadrupled?

11. A somewhat similar problem was presented to me when it was determined to construct the Manora break-water at Kurrachee, and the solution then arrived at by the Superintendent of the Works (Mr. Price) and myself is with certain modifications applicable to Madras. The Manora break-water, which has now advanced 800 feet from shore, has been subjected without material damage to much heavier and more continuous seas than a similar work would be subjected to at Madras, and it is in every way efficient as a break-water.

12. The principle is to form of the rubble-stone (which at Madras would be so costly) only a comparatively small submerged mound, the top of which is below the action of the waves, and to raise upon this a wall with vertical sides composed of large concrete blocks, each 27 tons weight. It is upon this wall alone that the sea has any action, and although the action is very violent, the great weight of the blocks is sufficient to withstand it.

13. Applying this principle to Madras, we should require, as compared with the Portland system, only about one-fourth the quantity of rubble-stone to form both the submerged mound and the bulk of the concrete for the superstructure, and the extra cost of cement and of labour in making and setting the blocks would still leave a large saving in favour of this principle, Taking as the basis of my estimate R8 per ton as the cost of rubble-stone, whether in submerged mound or in concrete, and the cost of cement and labour in making concrete and in setting the blocks the same as at Kurrachee, making also ample allowance for plant and preliminary works based on Kurrachee experience, I find that the cost of a break-water of the same length and in the same depth as Mr. Robertson proposes would be £566,000, or with 15 per cent. contingencies, £650,900, being about one-half of Mr. Robertson's estimated cost.

14. Mr. Robertson estimates six years as required for the construction of the break-water after the completion of the pier which he proposes to make for running out the stone upon. On the concrete block system it could be completed in three years after the completion of the pier, or, including the pier, say four years as against seven.

15. I submit, then, the conclusion that in considering the merits of Mr. Robertson's proposal for a break-water, the cost may be taken at two-thirds of a million, instead of one and a third million sterling, and the time occupied at four years instead of seven.

16. But I have now to show that even with these advantages the scheme is an unpromising one as compared with a rival proposal which Mr. Robertson somewhat summarily rejects.

17. At the time of Mr. Robertson's visit a report had recently been made by a Committee, of which the late Colonel Carpendale was President, which treated of the relative merits of a detached break-water and a "close harbour." I have not had an opportunity of seeing this report, but it appears, by a quotation from it made by Mr. Robertson, that the majority of the members, though on all other grounds preferring a close harbour, decided in favour of a detached break-water in extent and position similar to that subsequently recommended by Mr. Robertson, on the sole ground that they considered the close harbour would silt up. Colonel Carpendale, the President, did not concur in this, but maintained his preference for a close harbour, and Mr. Robertson himself thinks there would be "as much, if not more, danger of shoaling in the case of a break-water as of an enclosed harbour," giving his preference to the former on the alleged ground that it would afford more deep water shelter in proportion to the cost. But he makes his recommendation subject to such further information as may be obtained "as to the littoral currents and the quantity of sand in motion on the coast," as to the former of which he says there is "hardly a scrap of evidence."

18. But to my mind this very absence of evidence is the strongest possible testimony against the existence of a littoral current of such strength as could affect the present question. If there were so strong a current, it would be one of the most prominent and notorious features of the Madras coast. The evidence quoted by Mr. Robertson, and confirmed by Captain Taylor, of a well-known weak surface current to leeward in either monsoon, seldom running more than a mile an hour, though under rare exceptional conditions increasing to 3 miles an hour, proves conclusively the *absence* of any special movement of a kind unusual on a coast of this character. I am confident that there need be no hesitation in entirely disregarding these supposed littoral currents as vehicles for carrying sand along the line of shore.

19. The motion of sand along the coast by the oblique stroke of the breaking wave is a more important matter, but when Mr. Robertson expresses a desire for more information on this point, it is natural to ask how such further information is to be obtained. There is no doubt that the movement, whatever may be its extent, is confined to the belt of surf which fringes the coast, the width of which is said to vary according to the season from 300 to 450 feet, and in a less degree, perhaps, to a belt a little outside of it. It may be confidently affirmed that it does not extend to the contour of 30 feet depth, though it may possibly extend to 20 feet. Any deductions drawn from the effect produced by groynes which do not extend into the unbroken water are of little use, and an experimental groyne which would afford reliable evidence would be in itself a considerable work.

20. This being the case, it would appear that the testimony afforded by analogy should be examined before direct experiment is appealed to. Now, the testimony of the places which are most similar to the Madras coast, where the experiment has really been fairly tried, is, so far as I am aware, invariably to the effect that the quantity of sand or beach accumulated to windward of a groyne carried into deep water is not excessive or unmanageable. Port Said and Dover may be mentioned as instances which differ in almost every other respect, but agree in this, that the accumulation to the windward of the piers, though considerable, is not so great as to threaten to envelope the pier heads for generations to come. When the time does arrive, posterity will no doubt be in a position to grapple with the difficulty.

21. The position of the question at Madras appears then to be this: It is admitted that if a solid pier were run out from the shore, the beach movement of sand would be stopped by it, and an accumulation on one or both sides would be the consequence, but as to the amount of this accumulation, there is no definite means of judging. One party think it will be overwhelming, the other do not; the former opinion is supported by hypothesis only, the latter analogy. Nothing short of actual experiment can conclusively decide the question.

22. The success of the detached break-water scheme is, equally with that of the close harbour, dependent on the quantity of sand in motion by the oblique action of the surf not being excessive. Mr. Robertson says truly that the quieting of the waves on the beach would produce as effectual a stop to the movement of sand as a solid pier. Every wave would drive sand into the shelter, and there would be nothing to take it out again, so that the anchorage would be subject to a constant process of deterioration. I have already expressed my entire disbelief in the agency of a littoral current in moving the sand along the coast, and can see no ground for the suggestion that such a current would carry out the sand which the wave action would bring in.

23. I have now given the fullest prominence to the one legitimate doubt, on physical grounds, as to the success of a harbour at Madras, and I have shown that that doubt cannot be finally solved except by trial on a practical scale. A solid pier run out from the shore into 20 or 25 feet of water would bring the question to a practical test by showing how much sand would be collected in a single season. Such a pier would ultimately form part of the complete scheme if the result of the experiment encourage its further prosecution, and if it did not, the only loss would be the cost of the pier itself. Still, the experiment itself would be too costly to be advocated without a strong probability of a favourable result, but I think such probability is amply afforded by the analogy of similar situations. Taking the case of Port Said alone, I can imagine no unfavourable conditions at Madras which did not exist in a greater degree at that place, and yet the pier there is perfectly effectual in protecting the harbour from wave-driven sand.

24. I think, therefore, that, though this one doubt may justify hesitation in embarking in large immediate outlay, the probability of a favourable result is so strong that it is not premature to consider the principles of a complete scheme.

25. I have no hesitation in giving a preference to what is called a *close harbour* over a detached break-water. I cannot admit any fear of its shoaling, except from the remote possibility of the beach extending to the pier heads and entrance, which it could do only from an action which I agree with Mr. Robertson in saying would be equally, if not more, fatal to the detached break-water, if it be so to either. As to Mr. Robertson's assertion that a break-water would give more sheltered area, I confess myself unable to understand his meaning. Taking into account the completeness of the shelter afforded by the close harbour, and the consequent facility for mooring the ships more closely together, I consider the superiority very materially the other way.

26. The accompanying sketch shows (in yellow) the position of Mr. Robertson's detached break-water, and (in red) my own idea of a "close harbour," which would cost almost exactly the same money, *viz.*, £560,000, or, with 15 per cent. contingencies, £644,000. The system of construction for the piers would be the same as that described for the break-water, and, though the total length is greater, there is a saving from a portion of them being constructed in shallower water. The time required for completion would be about the same, namely, four years.

27. I have adopted this particular form, position, and dimensions for the harbour, not because I pledge myself to the opinion that they are the most suitable, but because, from the quality in scale and cost with the break-water which has been recommended by those who are more familiar than myself with the local requirements, it is more fairly comparable with that project. If the principle be accepted, there is great scope for variety in the arrangement of details.

28. It may be useful to point out the accommodation and facilities which would be afforded by such a harbour. It is obvious, from the proportion which the enclosed area bears to the width of entrance (450 feet), that the water will be almost as smooth as in a dock, whatever be the state of the sea outside. The existing pier might be used as a quay for vessels to come alongside to discharge and load, and additional jetties and quays could be made as required. In the deep part of the harbour there would be space for 28 or 30 of the largest class of merchant ships to swing at their moorings, besides those alongside quays, smaller vessels would be berthed nearer shore, and might be moored head and stern in tier, as in the Thames and elsewhere, where the shelter is complete.

29. The piers which enclose the harbour would not in the first instance be available for ships to lie alongside, but if further accommodation were required, they could be made so by carrying out new piers on the same system in the direction of the dotted lines. These new piers would then shelter the old piers, the vertical sides of which could, at a small expense, be made available as quay-walls and backed to any required width with sand or earth to form quays on which sheds and warehouses might be erected and trade carried on, on the modern system As another step in advance, the new pier might itself be brought into shelter by another further along the coast and converted into a quay-wall, a second and independent harbour being thus formed. This facility of extension, as trade requires it, is an important advantage.

30. I would repeat that the estimate of cost (as respects its largest item, the rubblestone) and the scale of the design are adopted rather with a view to comparison with Mr. Robertson's project than as being based on any information of my own. Mr. Robertson himself appears to think stone might be obtained at a cheaper rate, and, if so, both his and my estimates would be reduced; in fact, his would be reduced in a greater proportion than mine, and if stone could be got at R2-6 per ton, instead of R8, the two systems of construction would be equal in cost, [and the superiority on the ground of cost would then be on the side of the break-water over the close harbour. But such a low rate as R2-6 is hardly likely.

31. As to the scale of the design, I believe that within very wide limits it might be adapted to the amount that could be raised, and my expectation is that a design considerably smaller than that I have drawn would be more suitable to the existing state of the trade. Such a design would, of course, be equally capable of extension, when required, as a larger one. But it should be borne in mind that there is a relative economy in the larger scheme as the accommodation increases in a higher ratio than the cost.

32. If such a harbour as I have described were constructed, it is obvious that a material saving would be effected in the cost of landing and shipping cargoes, and in the time required for those operations. The risk to shipping would be reduced, and the facilities for repairs would be increased. All these advantages represent a direct saving of cost per ton of goods shipped and landed, and that saving might be appropriated to the payment of interest on the outlay. If this were sufficient for the purpose, the financial question would, I presume, be solved, and if it were not, there would still remain certain indirect advantages to the important interests of the town and surrounding country which are always more or less conferred by increased facilities of communication. These might be held to justify here, as they have been elsewhere, a charge upon the public revenue; but this is a question rather of administrative policy than of engineering, or even of finance, and which requires for a solution an intimate knowledge of the local circumstances of the country and of the trade.

Remarks by CAPTAIN A. D. TAYLOR, Indian Navy, on the above, 1872.

The great advantage of having Mr. Robertson's report, with a few glimpses therein of the opinions of the Break-water Committee, leads me unhesitatingly to prefer Mr. Parkes' idea of an enclosed harbour. The Committee have placed their opinion on record as follows:—

"If it were possible to construct an enclosed harbour which should be secure from the danger of shoaling up, we should not hesitate to recommend it in preference to a break-water. It would be greatly superior in every respect. The piers would be constructed from the shore and at far less expense, in proportion to the material used, than the break-water; the accommodation for shipping, and the facilities for landing and shipping cargo, would be greatly superior to those afforded by an open harbour."

To this I would add that smooth-water accommodation for landing and shipping cargo would be entirely provided under the first cost of the enclosed harbour, and wharfs might be constructed in smooth water; whereas, with a break-water all such accommodation would be an additional and quadruple expense, all piers for landing and shipping cargo requiring to be constructed in the open sea, and subject to havok from (if not east winds) at least from those strong north winds which usher in the Madras cyclones and from the S.-E. winds at their tail.

From a nautical point of view, let us consider the break-water question. Say it is complete, and several vessels are moored between it and the shore. The approach of a cyclone is indicated; the north wind, hourly increasing in force, gives warning that the vortex bears due east from Madras, and is advancing directly upon that place. Under such conditions the wind will remain at north till the centre of the storm arrives; when that has passed (with that awful half-hour of calm which "makes the boldest hold his breath for a time" in harmony with a hushed wind), and the cyclone is still travelling westward, the wind will come up from the south; if travelling more to the S.-W. the wind will be S.-E. What now becomes of all the smaller craft? How will the landing piers stand it? The small craft should have been sent to leeward on the rising of the north wind, to guard against the contingency of their parting from moorings and falling athwart hawse of the larger ships. Thus, after the passage of the vortex, when the wind has chopped to the S.-E. or south, and the storm wave comes on, they are found to windward. In the scramble to escape back through the shipping the foreseen contingency happens. Where are they now? Does the reader say, "This is mere hypothesis." Then let him listen to the chronicle of meteorological events published at Madras—

"Madras is occasionally subjected to various hurricanes, generally in the early part of May, or the end of October. They seem to travel up from the E.-S.-E., and progress rapidly in a W.-N.-W. direction till they touch the land, and then they assume a west or sometimes a W.-S.-W. course. Their centres generally come right on to the Port of Madras." * * * "Their diameters are about 150 miles, and they revolve in a direction contrary to the hands of a watch, as do all cyclones north of the Equator. When the hurricane's centre comes right on to Madras, and thence takes a west course, the wind is first at north, increasing in violence for a few hours, and then a full or awful calm for half an hour or so, when the hurricane re-commences furiously from the exactly opposite quarter, south. Usually the gale commences about N.-N.-W., showing that the vortex of the cyclone bears about E.-N.-E. Vessels, therefore, warned by the barometer, the hollow breaking surf, the threatening sky, and the signals of the watchful Master Attendant, should at once put to sea. The course to steer, and fortunately it is one which the wind permits, is S.-S.-E. to S.-E. In a few hours the vessel will probably have the wind moderate at west, and may, in fact it has been done, *sail round* the cyclone, the wind

veering to south and then to east. Vessels at first steering east to get way from the land have run right into the vortex of the hurricane! The only danger in a southerly course is from the storm-wave setting a ship on shore. If the gale commences N.-N.-W. at Madras, and ends at S.-E., as has often happened, it shows that the centre has taken a W.-S.-W. course, and passed a little to the south of the town, but if it ends at S.-W. it shows the centre has taken a W.-N.-W. course, and the vortex passed to the north of Madras."

We have ample reason, then, for thinking that the break-water system has few advantages to offer, nor is mine an isolated judgment. In a paper about Madras by my brother Captain J. H. Taylor (Messrs. Green and Co's. oldest Commander), his opinion is recorded that "from the exceptional bad weather caused by hurricanes or cyclones, no break-water would offer real security for ships."

Under the alternative system of an *enclosed harbour,* complete shelter is provided for both large and small craft. The Committee say that *the shoaling of the harbour would certainly result* from the construction of any solid piers or groynes from the shore. I know no reason why we should anticipate such a result unless pains were taken to bring it about by dilatory action in constructing the piers; thus, if 200 or 300 feet of each pier were completed, and then for want of funds a halt of an entire year was made, we might expect some sand to be brought from both north and south and left on the foreshore on the site of the proposed harbour between the piers. Tardiness in their construction before the zone of surf has been passed would be productive of mischief. But if both piers are rapidly carried out beyond the surf of ordinary weather, the littoral currents will not suffice to carry it past the pier heads, but merely a small growth of the beach, outside the piers and towards their ends, will be caused thereby. A very rapid filling up of such an angle was prognosticated as the result of constructing the break-water at Port Said, but time has shown that the operation of nature is very slow, and that the increased velocity given to the littoral current by the prominence of the pier suffices to carry on what sand is held in suspension by the agitated waves and past the entrance of Port Said. So would it be with a prominent enclosed habour at Madras, and I cannot share the fears of those who expect otherwise.

Memo. by Colonel G. W. Walker, R. E., Chief Engineer, P. W. Dept., Govt. of Madras, on Mr. Parkes' proposal for a Harbour at Madras, 1873.

Mr. Parkes' note on the formation of a harbour at Madras deals with two separate subjects:—

1st.—The principle on which a break-water should be constructed.

2nd.—The construction of a closed harbour instead of a detached break-water.

It is observed that Mr. Parkes' note was originally drawn up on the information gathered from Mr. Robertson's report, but that he has not in any way modified it after being supplied with the Break-water Committee's report. The objections to depositing the material of a break-water direct from a pier communicating with the land have not been entered into by him. There is no doubt but that by adoption of the mode of procedure made use of at Kurrachee, an immense amount of material will be saved, which ought to lead to economy and rapidity of execution—both very desirable objects. It is very expedient, therefore, that Mr. Parkes should visit Madras and endeavour to realize on the spot the force of the objections against direct deposit of materials from a pier, and to what extent they, if valid, would influence his calculations. He would then be in a position to estimate pretty accurately, with the experience gained at Kurrachee, the rates at which the lower portion of the break-water could be deposited of rough granite blocks, and the upper portion built up of 27-ton masses of concrete.

As to design, Mr. Parkes is opposed both to the former Committee and to Mr. Robertson, entirely disbelieving in the existence of a littoral current or other agency adequate to the moving of sand in such quantities, and so quickly, as to extend the line of shore as far as the extremities of any groynes that may be thrown out from it, within a moderate time. Even should such a contingency occur in course of time, he has no doubt but that it could be met, and its consequences effectually dealt with.

The conclusion arrived at by the Break-water Committee is that the inevitable result of the construction of a closed harbour on Mr. Parkes' plan would be the eventual extension of the beach and the complete closure of the harbour mouth, followed in course of time by the shoaling up of the harbour itself. Mr. Robortson, equally with Mr. Parkes, doubts the existence of sand-carrying currents capable of affecting the question of either description of work: but he prefers a break-water, and states that if a closed harbour be constructed, its mouth will have to be defended by a break-water.

That there is action of current and surf combined of a very decided nature along the coast of Madras, no one who knows the place can doubt. The effect of the vessels wrecked in May 1872, in acting as groynes, causing accumulation on one side and erosion of beach on

the other, has been manifest to the latest residents. It is, moreover, known that the effect of groynes thrown out with that view in front of Fort St. George has been to reclaim from the sea a sufficient width of beach whereon to form a broad roadway. But it is also known that such a reclamation takes up only a small portion of what was formerly dry land extending considerably to seaward of the Fort.

That there are considerable forces in existence acting on the sand cannot, therefore, be doubted, but the precise nature of their action has not been systematically noted, so that practical deductions may be drawn therefrom. It is very desirable that any Harbour Engineer who may be consulted as to the design and execution of a harbour at Madras, should reside there throughout a season to watch the effects of the changes of the monsoon currents, as well as to obtain information as to the cost of materials, carriage, and labour.

Should an open break-water eventually be determined on, it would be desirable that the economy of construction advocated by Mr. Parkes should be availed of to add to its length and place it in deeper water, rather than simply to reduce its cost. Should a closed harbour be finally approved of, it is probable that its shape will take that of two groynes projected into 6 fathoms water, headed by, but not connected with, a break-water in seven fathoms or more, so that there shall be two openings, north and south, not exposed to the direct action of the ocean swell.

A further memorandum by Colonel G. W. Walker, R.E., Chief Engineer, Public Works Department, Govt. of Madras, on Mr. Parkes' proposed Harbour at Madras,—dated 26th November 1873.

The plan of a harbour at Madras now submitted by Mr. Parkes is, as stated in his report, substantially the same as that submitted by him in August 1872, and recorded with G. O. No. 830 of 17th March 1873. That plan is of a close harbour to be formed by two jetties run out from the shore 500 yards north and south respectively of the present pier, to lengths of 1,200 yards, or into 7½ fathoms water; when they would be turned to meet one another, all but a space of 150 yards would be left for the entrance of ships. The method of construction to be similar to that adopted in the Kurrachee Harbour; and the cost £565,600, as against 1¼ million sterling, the estimate for a break-water.

2. Considering that this latter amount, in the opinion of the mercantile community at Madras, cannot possibly be raised without increasing the burthen of the port to an extent that would more than counterbalance any benefits that might be derived; and considering that in paragraph 40 of their report the Break-water Committee themselves do not hesitate to acknowledge their preference for an enclosed harbour, provided it were secure from the danger of shoaling up, Mr. Parkes' scheme has claims to special consideration both on financial and engineering grounds.

3. Mr. Robertson, in his report, was of opinion that "there may be as much, if not more, danger from shoaling in the case of a break-water, as of an enclosed harbour," but evidently does not believe in littoral currents of such velocity as to be capable of transporting such large quantities of sand as could practically endanger either work, although he desires further information on the subject of the currents and motion of sand.

4. In my memorandum of the 8th May 1872, on Mr. Robertson's report, I have stated my disbelief of any sufficient action of current and sand to affect either work; believing the true objection to a close harbour to be the nautical one of difficult entrance. The same opinions are stated in a letter to the Master Attendant of Madras, recorded with G. O. No. 1447 of 29th May 1873. And in the memorandum which accompanied the letter to the Secretary of State for India, No. 831 of 17th March 1873, I stated it to be probable that on nautical grounds the shape to be taken by a close harbour should be that of two jetties projected into 6 fathoms water, headed by, but not connected with, a break-water in 7 fathoms or more, so that there should be two openings for facility of ingress, and egress, not exposed to direct action of the ocean swell.

5. In his remarks printed with Mr. Parkes' letter of 29th September 1873, Sir Arthur Cotton distinctly repudiates the idea of either a close harbour or break-water as proposed being ever practically inconvenienced by shoaling up of sand. And he comes to the conclusion suggested by myself that, if two perpendicular jetties are used for construction of a closed harbour, their ends should not be joined, but covered with a break-water parallel to the shore, leaving two openings north and south, easy of access and sheltered from the swell.

6. In paragraphs 56 to 62 of Mr. Parkes' report are discussed the comparative advantages of one or two entrances. He shows that the danger apprehended from heavy seas rolling in directly through a single eastern entrance have been exaggerated from ignorance of the extent to which such seas become reduced as they spread over the still-water basin; and he claims for his single entrance loss of only half the mooring ground that has to be kept clear for ships to

bring up in. But he hardly states the case fairly as regards two entrances north and south, beyond which the break-water should project to an extent which would completely debar the admission of any sea. At the same time a double entrance and detached break-water would greatly increase the difficulty and expense of carrying out the work on Mr. Parkes' system, and if nautical men are satisfied as to the facility of ingress and egress by a single harbour mouth, it will be much more convenient to adhere to Mr. Parkes' design.

7. The use of laterite of the best quality in large blocks, for the rubble bases of his piers, 4 fathoms below the surface of the sea, appears to be unobjectionable; but it is doubtful whether he has sufficiently considered the details of that portion of the work which he proposes to construct entirely of laterite rubble from the shore into 4 fathoms water, through the surf.

8. The services of Mr. Parkes having been secured, by agreement with the Secretary of State for India, for 12 months after his return to England, in connection with this work, can best be utilized by requiring him to submit his design to the most competent nautical authorities at home for decision as to the entrance to be adopted, and his estimate to competent contractors, with whom he might be allowed to arrange for the execution of the work in the shape finally determined on.

Letter from the HON'BLE A. F. BROWN, Chairman of the Chamber of Commerce, Madras, to the Secretary to the Government of Madras, in the Public Works Department, communicating remarks on Mr. Parkes' scheme for a close Harbour,—dated 7th November 1873.

The Secretary of State having deputed Mr. Parkes, C.E., to visit Madras to report on the means of providing harbour accommodation at this port, the Chamber have gladly availed themselves of this opportunity to again take this important question into consideration.

2. Mr. Parkes at once most courteously placed himself in communication with members of the Chamber, and was good enough to attend a special meeting at the Chambers' rooms, and explain in detail his plans for providing a harbour for Madras.

3. Mr. Parkes is in favour of a closed harbour as opposed to the scheme of a break-water proposed by Colonel Orr's Committee in 1869, and without expressing any opinion on the engineering questions which the partisans of these respective projects have usually raised, the Chamber have no hesitation in saying that, on financial grounds, Mr. Parkes' scheme commends itself to their judgment above all others that have been brought under their notice. The Chamber may also remark that the information furnished by Mr. Parkes, as to the accumulation of sand at Port Said and other break-waters on sandy beaches, would seem to satisfactorily dispose of the silt question, which has proved such a difficulty heretofore in connection with any harbour plans for this port.

4. Mr. Parkes proposes to run two piers out, one 1,200 yards from the shore (the situation of the piers being 500 yards north and south respectively of the present screw-pile pier), and to connect them by a break-water running parallel with the shore. The space thus enclosed would, he states, provide a closed harbour with smooth water, which would accommodate 17 large ships at anchor in deep water, besides a number of native crafts in the shallow water near the shore. The piers would be constructed of blocks of concrete, weighing 27 tons each, and these blocks, it is understood, would be manufactured by a cheap and simple process in Madras itself. Whether a harbour of the above dimensions would be large enough at all times to accommodate the shipping of the port is open to doubt. But Mr. Parkes has explained that in case it should be necessary and desirable at any future time, either for commercial or imperial purposes, to increase the anchorage accommodation, the harbour could be easily enlarged by running out another pier from the shore to the north or south of the original harbour, and extending the break-water.

5. Mr. Parkes roughly estimates that the above scheme would cost about £565,000, a sum so moderate in comparison with the estimated cost of the proposed break-water that the Chamber trust that the Government may now see its way towards providing a harbour, the absence of which has so long been an obstacle in the way of the commercial prosperity of Madras, and a cause of such disasters to shipping during tempestuous weather. Indeed, the cost of the break-water seemed so excessive when contrasted with the trade returns of the port, that the Chamber, fearing the results of necessarily heavy port charges to pay interest on such a work, did not hesitate, in their letter of 6th July 1872, to recommend that it should not be undertaken except as an imperial measure. The estimated cost of Mr. Parkes' scheme, however, does not suggest such fears, and the Chamber are strongly of opinion that the trade of the port, whose growth, though comparatively slow, is steady, fully justifies the expenditure of £500,000 or £600,000 on a harbour. The Chamber quite agree with Mr. Parkes that so far as mercantile interests are concerned, the great object to be obtained in a closed harbour is the establishment of smooth water, whereby landing and shipping operations may be facilitated

and a considerable saving of time and money ensured. But while the Chamber willingly admit that the trade of the port should bear a fair share of the cost of such a work, they are of opinion that the many considerable advantages which the Government itself would derive from the harbour—whether as a refuge for ships in distress, as an anchorage for men-of-war, as a secure port for landing at all times and seasons troops or military stores, or as a means of improving the defences of the port—are an undoubted claim for a portion of its cost being borne by imperial funds, and doubtless in this view, which it is hoped will be accepted by the Government, it will be matter for consideration whether Mr. Parkes' scheme ought not at first to be enlarged, so that the harbour designed by him may be made of sufficient size to give much more accommodation than appears to be at present intended.

Letter from H. D. E. DALRYMPLE, Esq., Master Attendant, to Chief Secretary to the Government of Madras, Marine Dept., communicating remarks on the nautical bearings of the proposed new harbour at Madras,—No.7489, dated 20th December 1873.

I have the honour to acknowledge receipt of G. O., Marine, No. 306, dated 9th instant, referring Mr. Parkes' able and interesting Report on the formation of a harbour at Madras, for my opinion on the nautical bearings of the question. I shall notice in succession the paragraphs I do not entirely agree with, or explain them according to my lights on the subject.

2. I beg leave to preface my observations by recording that I am very far from being inimical to any scheme for the improvement of the *port* of Madras (which designation is, strictly speaking, a misnomer for an open roadstead), but I am bound, as the head of the Marine Dapartment of the Madras Presidency, to warn the Government against being committed to any incomplete scheme, which may eventually involve great additional expense.

3. In paragraph 14 of the Report under review, I quote the following passage :—"Advance of the beach involves a greater depth of water to be filled." Now, according to our experience, as the beach advances, of course so does the line of surf seawards, which stirs up the sand, deposits it, and the water *gradually* shoals. This throws a different light on the passage quoted.

Para. 15.—It appears to me that the *onus probandi* lies with the writer of this report; he should name a harbour constructed on a coast exactly similar to that of Madras (Coromandel), in the track of hurricanes, with a capricious surf, which is often impassable in a dead calm. The capabilities of the port of Port Said and Kurrachee are not possessed by the port of Madras.

4. *Para. 16.*—I also submit that the circumstances of the beach at Vizagapatam are entirely different. Sir Arthur Cotton's groynes are on the north side of the entrance of a harbour, in and out of which the tide flows and ebbs; and on the south side a precipitous bluff, called "the Dolphin's nose," rises out of the sea, with no beach at all.

5. *Para. 19.*—I agree with Mr. Robertson.

6. *Paras. 20 and 21.*—I am constrained to differ from the writer regarding a break-water. We require one to break the force of the sea, not of the wind; that is out of the question. The time or peril to shipping in the Madras roadstead is when the gale is dead on shore and the sea at its highest,* rolling right in on the land—*then* a break-water would be salvation to the shipping.

7. There is no danger from heavy sea from the northward; the trend of the coast is against it†: if a ship is uneasy, she can go to sea to the southward, having the advantage, when getting under weigh, of hauling out in comparative smooth water under the lee of the break-water‡; and if a heavy sea should set in from the southward, a ship has only to put to sea in a similar fashion to the northward. Yet I do not anticipate any such necessities.

8. *Para. 22.*—This is a simple question. You can to a certainty secure sufficient shelter if you have the break-water long enough, and you can, to supply additional shelter, adopt Captain Dickinson's plan (or something like it); *vide* his evidence before the Break-water Committee, or Sir Arthur Cotton's plan.

* I have seen green seas breaking over the T end of the pier, which is 15 feet above high-water level.

† Evidence by Colonel Orr, Chief Engineer, &c., &c., &c., before the Break-water Committee :—"No sea ever runs parallel to this coast."
Also *vide* Sir Arthur Cotton's opinions on the subject.

‡ *Extract from Sir Arthur Cotton's remarks on Madras Harbour.*

"In this respect I think there is an advantage in the highest degree in a parallel break-water permitting vessels both to enter and depart in all winds and in all weathers.

"In this important point no harbour can compare with a simple break-water parallel with a straight coast, and I suppose Madras with such a work would be the safest harbour in the world; there would not be the slightest danger in approaching or leaving it," &c., &c., &c.

9. *Paras. 27, 28, and 29.*—The writer in giving us three distinct classes of storms with directions of the wind on each occasion proves that only on the occasions of the gales of the 2nd class could the shipping in the Madras roads have been in danger, and had we during those gales had a break-water, in all probability not one ship would have been lost.*

* Under the lee of a break-water as a ship can veer away cable to any extent, the rise of the sea level is of no consequence.
In a close harbour the rise of the sea is fatal to ships "secured *closely* to fixed moorings."

10. *Para. 30.*—Here the writer is, I think, under a misapprehension. A cyclone of the 2nd class is, as a rule, at its height when the wind is dead on shore from the eastward ;† not at the "tail" of it, which is when it has veered round to the southward, and south-westward.

† Then the sea is always heaviest and very tumultuous.

11. *Paras. 41 and 42.*—It seems to have been overlooked that to those ships that cannot obtain room in the harbour and are obliged to lie outside‡ in the event of bad weather, the piers that form the harbour will be additional danger.

‡ In this proposed harbour space to be provided for only 16 ships, secured closely to fixed moorings.

12. *Paras. 44 and 45.*—It appears by these paragraphs that the piers proposed are to be so low,—only 3½ feet above high-water level,—that the weather side would be exposed to the sea washing over it, and that the ships will not be "removed from the breaking sea."§ This being the case, I should say that a ship would run less risk in an open roadstead without a break-water than if caught in such a trap.|| We all know that on this side of India in a violent gale or hurricane the waters rise considerably,¶ and if the sea walls or piers of the harbour be submerged, which they will be to a certainty, and the ocean wave rolls in clean over them, what chance of escape would there be for the shipping confined within the narrow limits of this harbour?

§ This in fine weather.

|| The safety of a ship in a hurricane is when she has room to veer away cable to any extent.
The *Hotspur* being at single anchor and able to veer away cable rode out the hurricane in the Calcutta river in October 1864. In previous hurricane, same month, all those at fixed moorings were either stranded or totally lost.

¶ I have a vivid recollection of the following disaster :—
In May 1833, the H. C. Ship *Duke of York* during a hurricane was blown from the Government moorings at "new anchorage," Saugor, thrown on her beam ends, and in that position driven on shore some 6 or 7 miles to the southward of Kedgeree.
When the waters subsided she was found high and dry in the jungle, at least half a mile from the water's edge.
Her tonnage was about 1,400 tons, and with 26 guns mounted, when the disaster occurred.

13. With reference to the above, I may refer Government to the Report of the Calcutta Cyclone of October 1864, on which occasion ships in the Hooghly, off Calcutta,** grouped at moorings, as proposed in the Madras Harbour, were driven from them, and rolled up in heaps along the banks of the river.

** *Extract of Report of the hurricane by the Master Attendant, Calcutta.*
"To give an adequate description of the disastrous effects of the cyclone upon the shipping is impossible."
"The ships were swept away from their moorings and driven or cast ashore in heaps in the opposite side."

14. *Para. 47.*—I do not understand the arguments in this paragraph; in a nautical point of view they are contradictory and unsound.

15. *Para. 51.*—*Vide* my foregoing remarks on paragraph 15.

16. *Para. 52.*—True : if a ship has a fair wind, room enough, and the gale not actually upon her.

17. *Para. 53.*—In regard to the first sentence of this paragraph, I refer the Government to the opinions of Sir A. Cotton, Colonel Orr, and the late Colonel Carpendale, the former Chief Engineer, and our present Chief Engineer and Secretary to Government, Department Public Works, &c., &c., &c. With reference to the last sentence regarding the infallibility of moorings, *vide* paragraph 13 of this letter.

18. *Para. 54.*—I have never understood that there was the slightest engineering difficulty in constructing a close harbour here; it seems to me that nothing could be more simple; but if we are to have one, it must be large enough to contain the whole shipping, and the piers or training walls must be *at least* 18 feet above high-water level, so as to keep the sea, when the waters rise in a hurricane, from breaking over them.

19. The Report under notice does not touch upon the expense of towing ships in and out of the harbour, or the hire of moorings.

20. The silt question I have avoided. Time will show who is right, and posterity will benefit by the question being solved one way or the other.††

†† *Query.*—As the shore at Madras was formerly great, in advance of the present line of coast, must it not follow that the sea has much powers by receding to reclaim as by advancing to abrade?

21. I beg leave to observe that while it has been my duty to draw the attention

of Government to the dangers and difficulties bearing on this particular scheme, having before recorded my opinions regarding it, I desire to state that if a close harbour be decided on I wish it every success, and all the assistance which it may be in my power to render towards the successful carrying out of the work shall be heartily given.

22. It is, however, my duty to add that the harbour scheme as now proposed is an incomplete one,* and it is beyond doubt that eventually it will be imperative on Government to complete it by raising the piers to a height of 18 feet above high-water level, and widening them, as already contemplated by the projector in paragraph 45 of his Report, which alone will nearly double the cost. Besides this outlay it will be found, in the long run, that, taking into consideration the cost of moorings, steam-tugs, and cranes† required, but not mentioned, which I estimate at three lakhs of rupees, this harbour of limited extent‡ will cost quite as much as a breakwater, while it can never be a harbour of refuge, and cannot afford the same amount of safety and accommodation as the work proposed by the Break-water Committee in 1869.

* *Vide* paragraphs 44, 45, and 46 in the Report.

† None of these appliances are required for a break-water.

‡ I would rather than this have merely a boat harbour, the outer sea wall being a continuation of the Tend of the pier.

23. In conclusion, I beg leave to state that no one can have appreciated more highly the projector's abilities and achievements as an engineer than I have, yet I may be permitted to point out that, as his stay in Madras was only during a few weeks of most exceptional and unprecedented weather for the season of the year, during which time, strange to say, he had only one opportunity of seeing an average monsoon surf, I am of opinion that those who have been familiar with the place for a long series of years may possibly be better qualified to judge of the requirements of the port. As regards engineering difficulties of any of the works proposed, there are none.

Memo. by Captain A. D. Taylor, Commander, late Indian Navy, on the Harbour for Madras,—dated 9th January 1874.

Considering Mr. Parkes' Report as quite exhaustive of the subject, and as conclusively demonstrating the superiority of an *enclosed harbour* with one eastern entrance, I might have let the question alone. But when we hear that "the principle of an enclosed harbour has been objected to *on nautical grounds*," it behoves me to explain that some nautical authorities think little of the principle of a detached break-water, but expect much benefit from an enclosed harbour.

2. Speaking of a breakwater, Mr. Dalrymple says, "it is thus far a certainty—the roadstead inside of it cannot silt up." But of the enclosed harbour he says, "it must be problematical."

3. I need hardly say that the break-water is the doubtful thing. Many enclosed harbours are in existence, but there is not one instance of a straight break-water lying off and paralle to a straight sandy shore. And I prefer the opinion of Mr. Robertson, C.E., that "there *may* be as much, if not more, danger from shoaling in the case of a break-water as of an enclosed harbour."

4. I append to this memorandum a transcript of the Admiralty Chart of St. Mary's Island, east coast of Madagascar, as exhibiting a most remarkable natural break-water, behind which, off the shore abreast, the sand has for centuries been accumulating into a point, which is by very slow degrees approaching the island; and we may reasonably conclude that precisely similar would be the operation of nature behind any detached break-water in the Madras roads.

5. I repudiate the notion that on *nautical grounds* there is an insuperable objection to such a form of harbour as Mr. Parkes proposes. If any objecting seaman would patiently examine his objections in the light of Mr. Parkes' able and exhaustive Report of November 4th, 1873, he would, I venture to think, find many of such objections groundless.

6. Precisely similar opposition was made to the wet-dock scheme for Table Bay, Cape of Good Hope. And even after the docks were finished, it was the custom of some—even nautical men—to predict disaster to ships entering the harbour. But when once a ship captain was found bold enough to attempt an entrance with a large ship under sail, the ice was broken and others followed to their own advantage.

7. I have no hesitation in declaring my belief that practical seamen would make no fuss about entering or quitting Mr. Parkes' harbour; that, indeed, it presents no inferiority on that score to any form of break-water whatever. I think that any *ideal advantages* which a vessel may have in entering or quitting the shelter of a break-water, are dependent upon the contingency of an *absence of any other vessels* to impede the progress of the in-coming or departing ship. Now, for such a ship Mr. Parkes provides a clear open area, more than two cables' lengths across, within the mouth of this harbour.

8. I think that Mr. Parkes has conclusively demonstrated the superiority of his proposed enclosed harbour in every way:—

Firstly.—In the greater area of *real shelter* afforded by his harbour in comparison with that which a one-mile straight break-water can afford (*see* paragraphs 20 to 22).

Secondly.—That the break-water *will not* (as suggested by Mr. Robertson) for an *equal sum* of money give much more *deep* water shelter than a harbour (*see* paragraph 22).

9. Let us look a little at the statement of Mr. Robertson that "vessels can enter and quit more easily from behind a *break-water* than through the one entrance of a harbour."

10. *Firstly.*—As to rounding the break-water in the north-east monsoon, November to March—the wind is from the sea, say, from any point between N. by E. and E. by S.—all that a sailing vessel can do is to anchor somewhere off the south end. Thence she must either be warped further in towards the centre, or be towed to a berth by a steam-tug. A steam-tug is preferable; warps will much hinder boat traffic.

11. It would never do to allow vessels to enter from the north whilst the current (as at that season) is running to south. At Calcutta the in-coming steamers are *not allowed* to come up above Garden Reach on a flowing tide; whilst outward-bound steamers (or ships with tugs) must move out from amongst the shipping only on the flood stream.

12. With the same wind a sailing vessel can easily enter the enclosed harbour, and drop anchor just inside. Then a warp will take her to her berth.

13. *Secondly.*—With a land wind from between N.-W. and S.-W. how could a ship with a W. by N. or W. by S. wind (with current running to north, as between May and September) venture to run in behind the *break-water* from the south? How could she find room to round-to and anchor? She *must* then anchor to the north of the break-water, and be brought in by a steam-tug.

14. With the enclosed harbour, ships arriving at the above time would anchor to leeward (either to north or to south and wait for a tug to take them in.

15. *Thirdly.*—With the normal "alongshore" south winds from mid February to April. The current then runs to the north, and vessels must not attempt to enter behind the break-water from the south, but they can only anchor to the north of it, and be towed in to a berth.

16. The same tactics are necessary for ships arriving under the same conditions of weather at an enclosed harbour.

17. *Fourthly.*—At the commencement of a cyclone, when the wind is between north and north-west, vessels must anchor to *leeward* of the *break-water,* and have a steam-tug to take them in. It would never do to allow them to run in from the northward at such times and to thread their way amongst the shipping (*see* paragraph 11). And it is certain that there would not be the ghost of a bit of shelter for them near the north part of a break-water.

18. Now, if the vessel seeking shelter could fetch to windward of Madras, she might bear up for the *enclosed harbour* on a south-west course under easy sail, easily could make the entrance, and, when within it, would put the helm down and let go the anchor about 250 yards to W. by N. of the north pier head. A vessel could even do this at night if red and green lights marked the two pier heads, and if it were an understood rule that a clear space existed.

19. But supposing that the vessel, in the above case, could scarcely fetch the entrance. Under the lee of the enclosed harbour the water would be smoother (for the operation of getting a hawser on board from a tug) than it could possibly be within the break-water when the wind is blowing fresh from N. by W. or N. by E.

20. After the evidence which Mr. Parkes has collected as to the prevalence of northerly winds at the cyclonic periods, we have good reason for doubting any realization of Sir Arthur Cotton's idea that "the break-water would leave the space behind it exposed to a *ripple* from northerly or southerly winds, but *not to any swell.*" Every sailor who has anchored for shelter to leeward of an island (and surveyors have more experience of this than others) knows that his vessel is not exempt from the swell that rolls in round both sides of the island causing her to roll, whilst the operation of landing (even along the island's leeside) is not such an easy thing after all. Anjedeva Island near Carwar and St. George's Islands off Goa well illustrate this point. I could cite many other instances from my experience of the West Coast of India.

21. Mr. Parkes has well explained in paragraph 21 that during the north-east monsoon the sheltered part of the beach would only be near the lighthouse, instead of opposite the business part of the town. Now, if the one-mile break-water be planted further northward to obviate this great objection, there would be no shelter at the site of the present custom-house from the swell which rolls up from southward during the prevalence of the south-west monsoon in the Bay of Bengal. And here I most heartily endorse Mr. Parkes' remarks in paragraph 31, about "preponderance of northerly winds and direction of waves."

22. Now let me ask this question. If the area to be sheltered by the original one-mile break-water of Sir A. Cotton and Mr. Robertson was not expected to suffer from any swell, why does Sir Arthur now speak of another form of harbour (noticed in paragraph 5 of the memorandum No. 75, signed by Colonel Walker, who states it as *probably a nautical requirement*), *viz.*, "two perpendicular jetties with ends that should not be joined but covered with a break-water parallel to the shore, leaving two openings, north and south, easy of access, and sheltered from the swell"? This modification of the *break-water* scheme transforms it into an *enclosed harbour*. But the entrance of such a harbour as this *cannot be* easy of access and at the same time sheltered from the swell.

23. Nor would it be convenient to let a merchant ship rush into the harbour and take up whatever berth she likes. Her berth must be settled by the Port Authorities, and it will be far more convenient that she should at first anchor outside and to leeward of the harbour, and from that position be taken in by a steam-tug.

24. Now we may say that the only question at issue is as to the *best form for* such *an enclosed harbour*. It is currently reported that Colombo is to have a break-water, and the inference is that what engineers have recommended for that place will suit Madras equally well. But the term *break-water* for Colombo is merely applied to the very same thing which Mr. Parkes has proposed for Madras, *viz.*, two piers starting from distant points of the shore, not meeting, but leaving a space between them of about 150 yards for the entrance of ships. There is this difference that Colombo has a bay, whilst the shore line of Madras is a straight sand, but the principle adopted for both places is identical.

25. Now I have to notice a statement that it is "an imperative necessity to have the entrance protected by a break-water." A similar prediction (which events have completely falsified) was made in the case of the docks at Table Bay, Cape of Good Hope. Some nautical men considered that, even through an opening of 300 feet, a considerable swell would sometimes roll in from the N.-E. round the other long break-water. But now the fact is established that each successive ocean-wave is completely broken against the vertical walls of the piers, and cannot become *re-united* to make head again, and to roll into the harbour. The original waves are effectually dispersed, and in the case of Madras Harbour the small derivative undulations having to spread out over two right angles, will be speedily reduced to insignificance, as Mr. Parkes explains in paragraphs 60 and 61.

26. As to the *accommodation* which Mr. Parkes' harbour will give us, I quite agree with all that gentleman says in paragraphs 22, 40, and 41 of his Report. Upwards of 30 ships could be well accommodated. And sailing ships during the fine season—waiting (as they now do) for many weeks before they can get a cargo—will find a pecuniary advantage in waiting outside in the roads.

27. After a consideration of all conceivable contingencies, it seems to me that the *single entrance* according to Mr. Parkes' plan is the best, and it must also be the most economical. At any rate, the *moot question* of entrance need not delay the commencement of the two piers from the shore, whilst Sir Arthur Cotton and Colonel Walker agree with Mr. Parkes in the preliminary requisites of a closed harbour.

Report by W. PARKES, Esq., on the formation of a harbour at Madras, dated Madras, 4th November 1873.

In accordance with instructions given to me by the Secretary of State for India, at the request of the Government of Madras, I arrived at this place on the 29th September, and was engaged for the five following weeks in prosecuting such personal enquiries, observations, and investigations as I considered necessary to enable me to submit to you my conclusions as to the best mode of providing shelter for shipping.

2. *Sources of information.*—I have received every possible assistance from the officers of all the Government Departments to whom I applied, from those of the Madras and Carnatic Railway Companies, and also from several of the leading merchants of the place, and from the Secretary of the Chamber of Commerce. I have also had opportunities of conferring with the Commanders of several of the ships lying in the roads at the time of my visit, and have received from them valuable information on nautical points.

3. *Previous study of the question.*—It is right that I should state at the outset that my attention had been given to the subject for some time previous to my receiving official instructions to report, and while in England I had the advantage of repeated conferences with Captain A. D. Taylor, I.N., an officer of great experience and eminence as a Marine Surveyor of this coast, and also with Mr. J. J. Franklin, R.N., for many years Secretary of the Marine Board of Madras, as well as with other gentlemen of local experience then in England.

4. *Invitation to visit Madras.*—As a result of the information thus obtained, I felt myself justified in submitting to His Excellency the Governor of Madras, in August 1872, some remarks, in which I called in question the correctness of certain conclusions which had then recently been laid before the Government and were under its consideration. It was, I believe in consequence of this that I was invited to undertake a personal investigation of the whole question on the spot. In doing this, however, I have subjected all my previous conclusions to the most rigid tests, and though those which I have now to submit are substantially the same, yet I am enabled to base them on information locally obtained, and I can put forward my recommendations in a more complete form, and my estimates of cost and of results to be obtained with greater confidence.

5. *Blackwood's Harbour and inland docks.*—I have not thought it necessary to devote much time to considering the details of two proposals which, in former times, have met with some support, because it had appeared to me that neither was calculated to effect the object in view, These are, first, the removal of the trade of Madras to some locality, such as Blackwood's Harbour, more favoured by nature; and, second, the formation of inland docks and basins.

6. *Break-water and close Harbour.*—The two proposals between which the choice now lies are, first, a breakwater entirely detached from the shore, and parallel to it; and second, a harbour formed by piers running out from the shore into deep water, and termed a "close harbour."

7. The former of these systems is advocated from two totally different and independent points of view, and, so far as I am aware, no one (unless the Master-Attendant, whose recorded opinion I shall presently quote at length, be an exception) advocates it on both grounds.

8. *Break-water Committee.*—The Committee appointed by Government in 1868 known as the Break-water Committee, reported in January 1869 as follows, paragraph 40:—"If it were possible to construct an enclosed harbour, which should be secure from the danger of shoaling up, we should not hesitate to recommend it in preference to a break-water. It would be greatly superior to the latter in every respect. The piers would be constructed from the shore, and at far less expense, in proportion to the material used, than the break-water. The accommodation for shipping and the facilities for landing and shipping cargo would be greatly superior to those afforded in an open harbour. But we consider that all these advantages would be rendered nugatory by the shoaling of the harbour, which would certainly result from the construction of any solid piers or groynes from the shore; and we are strongly of opinion that a break-water is the one work from which any real improvement is to be hoped." Such is the view held by one class of advocates for the break-water system.

9. *Mr. Robertson.*—Mr. Robertson, Harbour Engineer for India, says (Reports, first series, p. 62):—"I have come to the same conclusion as the Committee, but from entirely different reasons. I have shown that there *may* be as much, if not more, danger from shoaling in the case of a break-water as of an enclosed harbour; but taking all the circumstances connected with Madras into consideration, a break-water appears to me to be preferable to an enclosed harbour. For an equal sum of money it will give much more *deep* water shelter than a harbour; it will create a considerable length of sufficiently smooth water at the coast line to enable boats to land or to come to jetties, and vessels can enter and quit more easily from behind a break-water than through the one entrance of a harbour."

Thus, in Mr. Robertson's view, the shoaling objection would, if valid, be equally fatal to either system; but his opinion as to its validity, though not expressed, is, I cannot but think very clearly implied to be in the negative.

10. *Sir Arthur Cotton.*—Sir Arthur Cotton, in the able and suggestive paper he gave me before I left England, and which the Government at my request has printed and distributed, is less reticent. He argues from facts within his own experience that the alongshore movement of sand is not sufficient to interfere with the success of an enclosed harbour, but he prefers the break-water on grounds very similar to those expressed by Mr. Robertson, being mainly of a nautical character. Similar views are, I believe, held by others whose opinions are entitled to every consideration.

11. *Fear of shoaling groundless.*—I agree with Sir Arthur Cotton that the fear of shoaling, either in the case of a break-water or of an enclosed harbour, is groundless, and I agree with the Break-water Committee in their opinion as to the superior advantages of an enclosed harbour.

Advantages of break-water exaggerated.—I further think that both classes of advocates of the break-water have much over-estimated the advantages to be derived from it. I have now to give my reasons for these conclusions.

12. *Grounds of fear as to shoaling not definitely given.*—First, as to the fear of shoaling. The Break-water Committee and the professional witness by whose opinion they appear to have

been mainly influenced, Colonel (now Major-General) C. A. Orr, R.E., have expressed their conclusions upon this point in the most emphatic and confident terms. But in searching for the grounds of these conclusions one cannot but be struck with the comparatively hesitating and indefinite terms in which those grounds are expressed. The Committee, in their remarks on Mr. Fraser's project for a close harbour, say :—" We consider that there is strong reason to conclude that if a beach is extended a hundred yards by means of groynes, it might be extended a hundred yards further by continuing the process, and in each case a new line of beach being formed precisely similar to the original beach, there would appear to be nothing to prevent the shore being extended to any amount that might be desired."

13. *Colonel Orr.*—Colonel Orr passes over the matter very lightly in his evidence; but in a memorandum by him appended to the report, he says :—" It is evident to all who have had opportunities of studying the circumstances of the Madras beach, that any obstruction opposed to the currents must necessarily have the effect of arresting the passage of the sand which is in constant movement by the combined action of the surf and those currents, and of causing it to accumulate to windward of the obstacle. The accumulation would at first form merely an extension of the beach seaward in the angles between the training walls and the shore; but it would ultimately, I have no doubt, carry the line of the coast to the outer end of those walls, and close the entrance between them."

14. *Period required for advance of coast line not estimated.*—The natural process is, I believe, correctly described by Colonel Orr, but evidently the practical conclusion depends upon the meaning we are to attach to the indefinite term "ultimately." Does this refer to a future time to be reckoned by years, by generations, or by centuries? I presume that neither the Committee nor Colonel Orr can have meant to assert that the second hundred yards would accumulate as fast as the first, the third as the second, and so on. They cannot have failed to take into consideration that every hundred yards of advance of the beach involves a greater depth of water to be filled, and a greater length of coast to be covered by the triangular accumulation, and consequently a slower rate of advance for every successive hundred yards. But evidently they can have made no attempt to form even an approximate estimate of the decreasing rate of advance.

15. *Rate of advance decreasing.*—I might quote many instances of groynes, piers, and other obstructions carried out from sandy beaches similar to that at Madras, in which the rate of advance has been rapid at first, but in a few years so slow as to place the ultimate extension of the sand to the head of the obstacle in so distant a future as to render it practically no element in the question. It might be urged with respect to any one instance that the circumstances are different to that of Madras, but the cases are now so numerous as to throw the *onus probandi* on those who assert that Madras is an exceptional case. In some of the cases there were predictions of the same nature and as positive as those given in regard to Madras, but in every instance they have been signally falsified. There are plenty of instances of *small* groynes being buried and *small* harbour entrances being choked by sand driven along the beach as Colonel Orr describes; but in every case in which piers on a large scale have been carried out, the advance of sand has been left far behind. I spent much time before I left England in investigating the history of all the cases of which I could find any record, and satisfied myself that the general rule is as above stated, and that Madras might legitimately be concluded to be subject to the same rule, unless reason could be shown for its being an exception.

16. *Sir Arthur Cotton's experience.*—Upon this point the evidence of Sir Arthur Cotton is of the highest value. He had constructed groynes on the beach at Vizagapatam, and had carefully watched and recorded their effects. Those effects were of the same character as I have described above, and Sir Arthur had subsequently an opportunity, while Chief Engineer at Madras, of comparing the circumstances of that beach with those of Vizagapatam. He saw no ground for supposing them to be materially different, and unhesitatingly applied his Vizagapatam experience to the case of Madras.

17. *Records of effect of groynes.*—Since my arrival at Madras, I have gone a step further. I have searched the whole of the records in the Office of the Chief Engineer in connection with the accumulation of sand by the groynes constructed some years ago. I found it reported that when the groynes were short the spaces between were quickly filled with sand, but when they were longer, one season was not sufficient for the accumulation. On one occasion, in 1857, an estimate was made by Captain Rawlins, the Engineer in charge of the groynes, of the quantity of sand accumulated in a season by the groynes in front of the fort, and by that opposite the light-house, and those opposite Messrs. Arbuthnot's and the Custom House. The area was in the aggregate 22½ acres, and the depth 3 to 4 feet, and the spaces were not filled. Taking this, therefore, as a measure of the quantity of sand which could be arrested in one year, I

found that in order to fill in a triangular area of similar form between the coast and a pier extending 1,200 yards from shore, a period of 180 years would be required.

18. *Experience of other places.*—This result, though of course only approximate, is so completely in accordance with the experience of other places as to remove all doubt that the accumulation of sand at Madras will not be so rapid as to cause any practical inconvenience to a harbour formed by piers running out from the shore. I may mention three cases in which definite results have been obtained :—at the harbour of Great Yarmouth, on the east coast of England, exposed to a drift of sand from the northward, the drift was arrested for forty years by a pier less than 200 feet long; at the port of Bayonne in France, situated at the southern extremity of a line of several hundred miles of sandy coast, exposed to the heavy north-westerly seas of the Bay of Biscay, works constructed just within the shore line 300 years ago are now 1,200 yards inland; at Port Said, exposed to a constant drift from the westward, the experience of ten years furnishes data, according to the Admiralty Chart of 1870, for the conclusion that 150 years will elapse before the wave-driven sand can pass the pier head, which is now 2,200 yards seaward of the present coast line.

19. *Supposed advantages of break-water.*—I stated in paragraph 11 that I considered the advocates of the break-water had over-estimated the advantages to be derived from it. This conclusion is not based on the examination of any definite estimate of such advantages, for none such have been put on record, but rather from the statements of existing evils which it is assumed the break-water would remedy. The nearest approach to an estimate is that given by Mr. Robertson and quoted in paragraph 9, *viz.*, that it would give more deep-water shelter than an enclosed harbour of the same cost, and that it would create a considerable length of sufficiently smooth water at the coast line. Sir Arthur Cotton considers that 'the break-water would leave the space behind it exposed to a ripple from northerly or southerly winds, but *not to any swell.*"

20. *Want of data for estimating effect of break-water.*—These are certainly very vague estimates on which to base a recommendation for so large an expenditure, but that they are not more precise is due to the fact that there exists no experience, and even no theory on which such an estimate could be based. Mr. Thomas Stevenson, in his valuable treatise on harbours, states that he has "been unable to find that a single observation or experiment of any kind has been made upon the subject." That there will be some shelter behind a break-water lying parallel, or nearly so, to the ridges of advancing waves, we cannot doubt; but there are absolutely no means of judging better than the merest guesses to what extent the deflected waves will roll in through the wide spaces at either end, and what length of break-water would be necessary to prevent them from meeting in the space between it and the shore, and creating cross and confused seas more troublesome to ships, and more dangerous to boats, than the regular swell of the ocean. Were the length of break-water insufficient to allow the waves entering from either end to spend themselves, and leave a space between, in that space there will be complete shelter. Whether the length of 2,000 yards is or is not sufficient for this purpose, I cannot say positively. If I were to hazard a guess, it would be that it is insufficient.

21. *Direction of Seas.*—So far I have assumed that the seas will advance upon the break-water from that direction which gives it the greatest advantage, that is, at right angles or "broadside on," or in the case of Madras from the eastward. But it is evident that to a sea setting from the northward or the southward the break-water would be "end on," and of no use whatever. Probably no great force of sea ever comes from these quarters, but I am informed that during the north-east monsoon the waves, though breaking nearly parallel to the shore, have at the distance at which it is proposed to place the break-water, a direction much nearer to that of the wind which raised them, and would therefore strike the break-water very obliquely. This would reduce the width of the sheltered area, and the sheltered part of the beach would be somewhere near the light-house instead of opposite the business part of the town. A work which would offer so little protection during the annual foul weather season would not do much for the port.

22. *Comparative shelter of Break-water and closed Harbour.*—From what I have said of the uncertain character of the shelter to be obtained from a break-water such as proposed, it will be easily understood that I cannot bring to any definite test Mr. Robertson's opinion that it would provide more deep water shelter than a closed harbour of the same cost. I will, however, for the moment assume that the shelter would be as complete as its advocates appear to think. On such an assumption the number of ships that could be moored on the same system would be about equal in the two cases. On the most favourable assumption the break-water will not therefore give the superior accommodation claimed for it.

23. *Effect of Hurricanes.*—Sir Arthur Cotton says that this question of shelter for shipping is not to be settled by what happens in a hurricane. In this I quite agree. I doubt

whether any plan would give absolute immunity from danger during such exceptional times, still it is desirable to ascertain precisely what are the dangers to which shipping are exposed at such times, and what will be the effect of works intended for their protection in more ordinary times.

24. *Description of Hurricanes.*—I think, with this view, it may not be without use for me to present, in a more definite form than is ordinarily accessible, the leading features of the hurricanes which occasionally visit Madras. It does not fall to the lot of many persons to be eye-witnesses of more than one or two of these severe storms, and this partial experience is apt to lead, either, on the one hand, to a too hasty generalization, or, on the other, to an equally hasty conclusion that the phenomena manifested are incapable of being definitely classified.

25. *Observatory records.*—To enable me to do this I have been favoured by Mr. Pogson with not only a sight of the very complete meteorological records of the Government Observatory, but also with his personal assistance in extracting from them the leading features of the several storms which have occurred since 1787, a period of over three-quarters of a century.

26. *Three classes of Hurricanes.*—I give in an Appendix the extracts which he made, and I now submit the general conclusion to be drawn from that statement. A very little study of it will show that the storms may be divided into three distinct classes, and the generally accepted theory of revolving storms or cyclones, identifies these classes as those in which the centre of the storm passes respectively over Madras, or south, or north of it.

27. *First class—central.*—Storms of the first class occurred in October 1797, May 1811 October 1818, and October 1836. In all these cases the wind commenced at or near north, blew for some hours with great force, then there was a lull of half an hour or less, and then it blew again with equal violence from the south. In no case, except perhaps in 1811, as to the particulars of which there appears to be some doubt, did the wind come at any time from the eastward.

28. *Second class—Centre south of Madras.*—Storms of the second class, centre south of Madras, occurred, in December 1807, November 1846, November 1848, May 1850, November 1864, November 1865, and May 1872. In each of these seven cases the same course was followed, the wind rose at about north, then gradually increasing in force it veered towards east, maintaining its force. After passing east it gradually fell, and by the time it arrived at south was either very light or merged in the ordinary periodical wind.

29. *Third class—Centre north of Madras.*—Storms of the third class, centre north to Madras, occurred in November 1787, May 1788, March 1820, May 1820, May 1827, May 1841, May 1843, October 1846, May 1851, and November 1856. In these ten cases the courses of the wind were much less regular than in the two preceding classes. It kept rapidly shifting about with apparent irregularity through the *western* half of the compass, never during the height of the storm being in the *eastern* half, except on one remarkable occasion (October 1846), and perhaps one or two other of the earlier ones, when it made a rapid circuit of the whole compass round by west, north, east, and south.

30. *Summary.*—It thus appears that in only one out of the three classes (with the one exception just noted) did the wind blow from the east, in only one from the south with any force, but in all from the north. I may add that strong winds never blow from the eastward at Madras except at the tails of the one class of cyclones.

31. *Preponderance of northerly winds—Direction of waves.*—This statement shows that in extraordinary as well as in ordinary weather there is a great preponderance of strong northerly wind. During ordinary times it is the north-north-east wind of November and December alone, or rather the sea raised by it, which interferes in any serious degree with the trade of the port as carried on on the present rude system. It is of course from the waves rather than from the wind that shelter is required, and these no doubt in the gradually shoaling water advance from a more easterly quarter, but the assumption that they come from a direction nearly at right angles with the proposed break-water is not borne out by the information I have received. If the question between a break-water and an enclosed harbour depended upon this, it ought to be made the subject of more systematic observation before assigning any precise weight to the argument, but I have no hesitation in saying that a roadstead exposed to the most prevalent and strongest *wind*, even irrespective of the direction of the heaviest *seas*, cannot be considered to be effectually sheltered.

32. Having now shown that the only objection to an enclosed harbour which has been put forward as fatal, is groundless, and that the advantages to be derived from a break-water are very uncertain as to their extent, and on the most favourable assumption very incomplete, it only remains for me to describe the work which I consider most suitable to the locality and the circumstances.

33. *Principles on which design is based.*—In determining upon the scale of my design, I have endeavoured to keep in view the following principles: first, that it should be sufficient for, but not in excess of, the present requirements of the trade; second, that it should be capable of extension if it should become necessary to provide for an increase of trade, or greater accommodation for shipping; and, third, that the outlay upon it should not render necessary increased expenses in the trade of the port, so as to enhance the cost of goods exported or imported, or throw any permanent burden on general or local revenues.

34. Whether this last condition is absolutely necessary it is not for me to say, but if it can be fulfilled it is undoubtedly a desirable one, as it would render the undertaking at least self-supporting, if not pecuniarily profitable.

35. *Source of Revenue.*—The source to which I look for revenue to pay interest on the necessary outlay is the appropriation of the saving which may undoubtedly be effected upon the expenses to which the trade is exposed by the present rude system of landing and shipping cargoes. This is not only very costly in itself, but it subjects the cargoes to much damage in their passage between the ship and the shore; and by the slowness, awkwardness, and uncertainty of the operation, causes great detention of the ships. The removal of all these evils may be represented by a money value which may in some form or other be carried to the credit of a harbour revenue.

36. *Present system very expensive.*—In what particular form the charge should be levied is for the present an immaterial question. I am now only concerned to show that such a saving is possible, and that it would be on a scale commensurate with the required interest on the capital to be sunk. In proof of this I would refer to the accompanying table which shows the comparative cost by official tariff of landing and shipping cargo at Madras as an open roadstead, and at Kurrachee a smooth-water harbour. The charges for lightering to and from the roads outside the harbour at Kurrachee (now however never incurred) are given to show their general coincidence with the Madras charges under similar conditions.

Comparison of the Cost of Landing and Shipping Cargo at Madras and at Kurrachee from Official Tariffs.

	Madras.	Kurrachee.	
	Fair Weather.*	Harbour.	Roads.
Imports.	R a. p.	R a. p.	R a. p.
Piece goods per 100 bales	34 6 0	25 0 0	35 0 0
Grain per 100 bags	11 0 0	4 0 0	10 0 0
Beer „ „ hogsheads	45 12 0	15 0 0	25 0 0
„ „ „ barrels.	22 14 8	10 8 0	20 0 0
Iron „ ton	1 14 0	0 12 0	......
Coal and coke per ton	1 6 0	0 12 0†	......
Exports.			
Cotton and wool per 100 bales	27 8 0	12 0 0	20 0 0
Grain per 100 bags	11 0 0	3 0 0	10 0 0
Oil „ „ hogshds.	45 12 0	12 0 0	20 0 0
Ghee „ „ dubbers	11 0 0	8 0 0	18 0 0
Hides „ „ bales	34 6 0	20 0 0	40 0 0

	R a. p.
* Boat	2 8 0
Police Peon	0 3 0
Tarpaulin 4a (occasional)	0 1 0
	2 12 0 for 2 tons.

† Exclusive of cooly hire for discharging from lighters.

37. *Cost at Madras with a Harbour.*—I believe the actual charges at Madras with a smooth water harbour would be less than at Kurrachee, as at the latter place the distance for lighterage is from 2 to 3 miles, whereas at Madras it would be about half a mile, and also the supply of skilled boatmen is more limited. I have based the Madras charges on the

tariff for Masula boats to the beach. The charge to the pier is less by the amount of pier due, which equalizes the cost to the trader. If the pier were enclosed in a harbour, ships would come alongside of it, and discharge direct, and so would save lightering altogether, thus giving to the pier an advantage equal to that given to the breach-landing system. I am informed that some merchants have contracts with the Masula boatman at less than tariff rates, but, on the other hand, there are frequent extra rates, so that the tariff may be taken as a fair average.

38. *Estimated amount of saving.*—I believe that in assuming the saving in landing and shipping operations, and other consequent expenses, at *a rupee per ton of goods*, I am under the mark, but assuming this figure, and applying it to the lowest estimate given of the number of tons landed and shipped last year, *viz.*, 2,75,000, we may rely upon a revenue derived from savings only of £27,500. This would pay interest at 4 per cent. on £6,87,500; at 4½ per cent. on £6,11,000, and at 5 per cent. on £5,50,000.

39. *Estimated cost of Works.*—A harbour made according to the accompanying plan would cost £5,65,000, including 10 per cent. for contingencies and 5 per cent. for superintendence, and therefore seems to be within the resources of the trade of the port. It is intended to be formed by piers running out from the shore 500 yards north and south respectively of the present screw-pile pier, enclosing a rectangular space of 1,000 yards long by 830 yards wide, or 170 acres, with a depth at low-water of from 3 to 7 fathoms, and consequently available for European ships of all sizes, with a further space of a quarter of that area with a depth less than 3 fathoms, available for boats, lighters, and native craft.

40. *Accommodation in Harbour.*—Such a harbour would contain 13 ships of various sizes, from 4,000 to 700 tons, secured closely to fixed moorings, and able to swing, each in its own circle, clear of one another, also three ships alongside the pier, making 16 in all. If the ships were more closely moored so as to swing clear of the next ship's mooring, but not of the entire circle she would describe in swinging, the number would be increased threefold. This I am myself satisfied might be done with safety, since ships would be completely cut off from the strains and unequal disturbances of swell and current, and acted on only by wind. But this is rather a matter for the consideration of the Nautical authorities, and its determination is not urgent.

41. *Accommodation for maximum number not required.*—Taking, however, 16 ships as the limit of the capacity of the harbour, I am informed that more than this number has been in the roads at one time on certain extraordinary occasions. I do not think, however, that it would be wise to incur the expense of providing for a repetition of such extraordinary contingencies. In the first place they are not likely to occur again unless as a consequence of a great increase of trade, because the effect of the increased employment of steamers is to facilitate the despatch of vessels from the port and leave room for others, and this despatch will be further facilitated by the improved system of landing and shipping cargoes. In the second place, such a press would only occur during the most busy season, which is also the fine season, when ships would be as safe as they are now outside the harbour, but would have the advantage of the improved system of lightering to facilitate their despatch. I therefore think that the additional expense which would be incurred by enlarging the harbour, so as to contain the maximum number of ships on record, would not produce any commensurate advantage.

42. *Possible extension of accommodation.*—But though I do not think it would be wise to incur expense in anticipation of increased trade, a policy which has often defeated its own object by crippling the immediate resources of the port, it is yet of the highest importance to be prepared for future extensions whenever increased trade or other circumstances may demand it. This has been specially kept in view in designing both the plan of the harbour and the details of construction.

43. *Section of piers.*—It will be seen, by reference to the section of the piers appended, that they are proposed to be formed of a submerged mound of rubble stone from the natural bottom to a depth of 22½ feet below low-water. Above this they will consist of two solid walls of concrete blocks laid close together so as to form one wall, 24 feet wide. This is very similar to the system followed in the case of a break-water lately completed at Kurrachee.

44. *Not in the first instance available as quay walls.*—The two faces of such a pier are of such a character that ships might come alongside them, but it would be useless for them to do so, because the width of the pier, 24 feet, is insufficient for the purposes of a quay, and that on the weather side of the harbour would be exposed to the sea washing over it. To make the piers available as quays in the first instance would involve an additional cost, for which I do not think there would be an immediate equivalent.

45. *Quays to be ultimately formed.*—But I look forward to this as a second step, which in due time will be very advantageous. The pier as first constructed would be a mere sheltering break-water. When the trade requires more accommodation, I propose to form another similar

sheltering break-water at a distance of, say, 100 yards from the first, and parallel to it, as shown by the dotted lines on the plan. The original pier would then be so far removed from the breaking sea that ships might lie alongside without inconvenience, and the space between the two parallel piers being wholly or partially filled up, a wide quay would be formed, on which goods might be landed and on which sheds and warehouses might be built, and thus greatly improved facilities for carrying on the business of the port would be provided. Such a quay wall would accommodate six or seven ships alongside of it in addition to those swinging at moorings.

46. *Further extension of works as may be required.*—Should the extension of trade require still further accommodation, a second harbour similar to the first could be formed north or south, one side being already provided by the pier and quay of the first harbour. For the present, however, it is enough to consider the merits or demerits of such a scheme as the present trade of the port is adequate to support.

47. *Facility for entrance and exit of Ships.*—I have already said that the principle of a closed harbour has been objected to on nautical grounds, and the preference given to a detached break-water, because ships can enter or quit more readily in any wind. This argument would apply with still greater force in favour of the proposal to leave the roadstead in its present exposed state; for I fear there is no getting over the objection that every obstacle to the entrance of waves is, to a certain extent, an obstacle to the passage of ships. A ship, however, is more easily guided than a wave, and the objection, whatever it may be worth, becomes simply a question of the cost of employing steam-power. It is, however, in my opinion, worth very little.

48. *Objections urged by the Master Attendant.*—In order to give the fullest prominence to the objections made, on nautical grounds, to the principle of a closed harbour, and especially to the special form I have adopted, I append a report by Mr. Dalrymple, the Master Attendant of Madras, commenting on my first proposal, but in terms which are equally applicable to the present:—

"I have the honour to acknowledge receipt of the papers specified in the margin, and to offer a few remarks on the project for the formation of a close harbour at Madras.

"2. I shall first deal with Mr. Parkes' letter and his able "Note" in a nautical point of view, without presuming to touch on the engineering phase of the question.

"3. In paragraph 11 of his "Note," he is, I think, in error in assuming that at Kurrachee there is a heavier sea than at Madras. In cyclones and gales of wind on this coast the storm-waves cannot be surpassed.

"4. With reference to paragraph 21, I have only to state that, according to our experience and my own personal observation, every groyne, which has been run out from the old sea wall, *viz.*, the "DeHavilland's Bulwark," has carried the beach along with it, the longest groyne being about 400 feet in length, and consequently, as the shore has gained on the sea, the line of surf has moved out in proportion; and it is a question yet to be solved how long this same natural action of the elements will continue as similar works are pushed on seaward.

"5. In regard to paragraph 23, I cannot see that the position of Port Said and its natural advantages added to the Suez Canal are at all analogous to those of Madras, which are simply *nil;* the attraction of the latter port being its cheapness and easiness of access, it being an open roadstead.

"6. I concur with Captain Taylor in some of his opinions; yet my own opinion is this that, if we are to have a gigantic work for the protection of the shipping, a break-water is the best. It is thus far a certainty—the roadstead inside of it cannot silt up, and it will be a protection from the heavy break of the sea in a gale, when the wind is dead on shore, which is the time of peril to shipping.

"7. The success of an enclosed harbour is supposed by numbers to be an impossibility; at all events, it must be problematical.

"8. I may also remark that during a gale, while a ship could run in under the lee of a break-water for shelter from the *heavy sea,* she could not run into such a harbour as that proposed by Mr. Parkes.

"9. With reference to memorandum by the Chief Engineer and his letter to the Head of the Marine Department, dated 5th April 1873, No. 128, I entirely agree with his views on the subject. If there is to be a harbour, it will be an imperative necessity to have the entrance protected by a break-water; otherwise in a gale the heavy sea will roll in, and the ships in that confined space will grind each other to pieces, being in a much worse position than in an open roadstead.

"10. I also entirely agree with the Chief Engineer regarding the nature and extent of our littoral currents and in his judicious recommendation that Mr. Parkes should reside in Madras for a year or so to watch the currents, etc.

"11. I may remark that these are at times so very strong that the boatmen will not float their boats unless the strong current flag is flying at the Master Attendant's flagstaff, which entitles them to double hire. I think this is pretty conclusive evidence that these currents exist.

"12. With reference to the last paragraph of letter referred to, in the event of a harbour being constructed, tug-steamers will be required to tow the ships in and out of the harbour in fine weather, and it will depend on the space which will be decided on for the inside area of the harbour, as to the number of ships which can be berthed alongside the jetties and moored head and stern in the basin.

"13. In conclusion, I may observe that, while I give the preference to a break-water as a more suitable work for this port than an enclosed harbour, and while I fully admit that it would alter greatly for the better character of the roadstead, it is yet to be borne in mind that, should any costly works be carried out, the interest of the outlay must be provided for by an increase of rate of port-dues; and in these days of railway progress,

and consequently increased facilities of communication to and from out-ports, is it not to be expected that, in the circumstances, a considerable proportion of the Madras trade would too probably go elsewhere?"

49. *Remarks on the Master Attendant's Report.*—With respect to paragraph 3 of the above report, my statement of the comparative force of the sea at Kurrachee and at Madras was based on information obtained from persons well acquainted with both coasts; but the principles of my design are in no way dependent upon its being correct (see paragraph 61 further on).

50. I have already entered fully into the subjects touched upon in paragraphs 4 and 5.

51. With regard to paragraphs 6 and 7 it is remarkable that, considering the number of existing close harbours in all parts of the world, the success of the principle should be deemed problematical, while a scheme for which there is not a single precedent to be found in nature or art,* should be pronounced certain of success.

52. The opinion given in paragraph 8 will no doubt have its due weight. I will only state here that it is opposed to that of every nautical man with whom I have conversed on the subject, and that, as a matter of fact, ships do continually enter harbours similar to that I have proposed in very heavy seas.

53. As to Mr. Dalrymple's proposed break-water to shelter the entrance, I do not myself think it would be either necessary or an improvement,† and this is the opinion of most of the competent persons with whom I have conversed on the subject; but it is a mere matter of detail, which may best be settled by actual trial of the effect of the entrance without a break-water. As to the ships in the harbour grinding one another to pieces, I need only refer to the plan which shows how they would be moored.

54. With regard to paragraphs 10 and 11, I may remark that I do not question any of the *facts* given me by the Master Attendant and other competent persons as to the littoral currents. I only maintain that they do not present any difficulty to the construction of a harbour, or to its use when constructed. As to the nature of these currents, and as to their having no effect whatever on the bottom outside the line of surf, I believe Mr. Dalrymple and myself are entirely agreed. This being the case, it is difficult to see what object would be gained by my spending a year or so in watching currents, &c., which are already so familiarly known to Mr. Dalrymple and others, and, it is admitted, have little or no bearing on the question.

55. I entirely agree in the principle laid down in Mr. Dalrymple's last paragraph that an increase of port expenses would be detrimental to the trade of Madras, but I have shown that the plan I propose can be carried out without any such increase.

56. *Entrance to Harbour.*—Having now stated the grounds on which I venture to think that the objections to the general principle of an enclosed harbour are untenable, I proceed to consider a point of detail which has been made the subject of some discussion. I allude to the position and form of the entrance or entrances.

57. *Comparative advantages of one and two Entrances.*—The plan which I submit as being, in my opinion, on the whole the best has an entrance 150 yards wide, facing east by south. The alternative plan is to have two entrances at or near the outer angles of the harbour. The one undisputed advantage of this latter plan is that vessels could enter or leave by one entrance or the other with any wind. The one undisputed disadvantage is that, inasmuch as a sufficient space must be kept clear in the neighbourhood of each entrance for ships to bring up after entering the harbour, the space required for the second entrance would be lost as mooring ground.

58. *For the entrance and exit of Steamers and Ships.*—These two considerations are inseparable from the very principles of the two systems, and the respective evils cannot be averted by any arrangement of detail. We can only endeavour to estimate their relative value. The disadvantage of the double entrance is simply this—a sacrifice of one-fifth or one-sixth of the capacity of the harbour. The disadvantage of the single entrance will be different for different classes of vessels. For *steamers*, the most important class, it would be *nil*. *Large sailing vessels* could enter or leave without steam power with the wind in 18 out of 32 points of the compass. In the remaining 14 points either way a steam tug would probably be required. But it must be remembered that with an on-shore wind a large outward-bound ship would probably take a tug to get an offing, quite independent of the question of clearing the harbour, while to an inward-bound ship, with an off-shore wind, there would be at least smooth water and good anchorage till she could be towed in.

59. *For Native Craft.*—*Native craft, outward-bound,* could certainly sail out of the entrance whenever they could beat off the shore, and *inward-bound,* with an off-shore wind,

* I cannot admit the resemblance suggested by Sir Arthur Cotton between a break-water a mile long, and the formation known as "barrier reefs" generally extending for many miles.

† See paragraphs 61 and 62 further on.

they could bring up, if unable to enter the harbour, on the more sheltered side, north or south and either discharge there or warp in at leisure. I, therefore, cannot estimate the disadvantage of having only one entrance as being of much practical importance to any class of vessel.

60. *For protection from Seas with one entrance.*—More importance has probably been attached to another objection, which, however, I cannot admit as undisputed, *viz.*, the danger from heavy seas from the eastward rolling into the harbour. Those who urge this objection are probably not fully aware of the effect produced upon such seas when they enter a harbour. They are immediately dispersed, and the extent of reduction is not, as in the case of an open break-water, a matter of speculation, but it is one of exact calculation.* Captain Biden, the former Master Attendant, estimates the maximum height of wave at Madras at 10 feet. Such a wave entering the harbour would be reduced to 1 foot 9 inches before it reached the piers or the beach. A wave 15 feet high (the maximum measured at Kurrachee) would be reduced to 2 feet 7 inches—neither very formidable.

61. *With two entrances.*—Whether the two entrances would admit more or less swell with an easterly sea would depend on their width and form. If equally accessible to vessels as the eastern entrance, they would, I believe, together admit more sea, and the reductive power of the harbour would be less, as each wave would spread over only one right angle instead of two right angles.

62. *Effect on Seas from different directions.*—With the north-east monsoon swell the eastern and northern entrances would be about on a par, but the former would have more reductive power. If the tranquillity of the harbour were inversely proportioned to the duration and force of the wind to which the entrances are respectively exposed, the easterly one would have a marked advantage over either of the others separately, and of course in a far greater degree over the two together,† but the easterly seas are the heaviest and most dangerous, and go far to counterbalance this advantage. On the whole, however, I am of opinion that the balance of advantage is on the side of the single entrance facing east by south.

63. *Details of execution—Granite.*—I have now to offer a few explanations as to the details of the mode of carrying on the work. The great bulk of the material required is of course stone. I have visited St. Thomas' Mount and Palaveram to the south, and the Red Hills, Avady, Umbatoor, and Seetapetty on the west of Madras. In the former direction the material is granite, and might be brought in any quantity by the Carnatic Railway now under construction, but it is so exceedingly hard that it would be very expensive to quarry, and would probably come out in blocks of inconveniently large size. I, therefore, discard this source of supply.

64. *Laterite.*—At the other places the material is laterite, of which the best quality would be very suitable for those parts of the work where great hardness is not essential, such as the curved approaches to the piers, which I propose to carry over the shifting sand near the shore, as simple embankments of rubble stone, and for the rubble bases of the piers themselves. The Break-water Committee very wisely rejected the use of this material, as in their section it would be exposed to the destructive action of the waves, for which it is not sufficiently hard. In my section it will not be so exposed, and with due care in selection it may be used with perfect confidence.

65. *Conveyance by Railway.*—A branch from the Madras Railway at Umbatoor, nine miles from Madras, running northward for about two miles, would cut through an ample supply of this material, which the Railway Company would bring to the very site of the works.

66. *Trittany Granite for Concrete.*—For the bulk of the concrete I have estimated for a better material, granite from Trittany, 50 miles from Madras, but I think it not impro-

* Stevenson on Harbours.

† *Abstract compiled from Observatory records.*

Wind.	——	1870.	1871.	1872.
N. by W.—N. . . . N. by E.—N. N. E. . N. E. by N. . . .	Duration . . Mean rate . .	1,741 hours . 7·2 miles .	1,213 hours . 6·6 miles .	1,360 hours. 7·35 miles.
E. by N.—E. . . . E. by S.—E. S. E. . S. E. by E. . . .	Duration . . Mean rate . .	1,124 hours . 5·7 miles .	1,192 hours . 5·7 miles .	1,215 hours. 5·8 miles.
S. by S.—E. . . . S. by W.—S. S. W. . S. W. by S. . . .	Duration . . Mean rate . .	1,420 hours . 7·6 miles .	1,483 hours . 7·85 miles .	1,339 hours. 8·4 miles.

bable that even for this purpose laterite would answer, and, if so, a saving on the estimate would be effected.

67. *Beach Railway.*—A line of railway would require to be laid along the beach for the conveyance of the stone to make the curved approach to the south pier, and for the concrete blocks for the superstructure of the pier itself, but the whole of the rubble stone for the bases of both piers would be placed in boats (probably steam hopper barges) at the north pier, so that after the curved approach was completed, the traffic along the beach railway would be very limited.

68. *Concrete-mixing Station and Stacking Ground.*—There appears to be no difficulty in a portion of the beach north of the railway station being occupied by the necessary concrete-mixing establishment and ground for making and stacking the blocks. Branch railways would, of course, be laid for the conveyance of materials.

69. *Time of completion.*—The first operation would, of course, be the formation of the curved approaches. These might be commenced immediately, and while they are in progress the necessary plant and machinery could be collected. The actual building of the piers could be completed in three years, or, say, four years from the time of the approaches being commenced.

70. *Remarks on Estimate.*—The estimate of £565,000 is, I consider, a safe one, and is based on a fair allowance for the increase of ordinary rates which generally accompanies the execution of so large a work. In the event, however, of the work being placed in the hands of any other engineer, a new and entirely independent one should be framed by him, but I see no reason why it should exceed mine.

71. *Survey required.*—Before any works are commenced, it is most desirable that a new and detailed survey of the roadstead should be made, the soundings of which should be referred to a permanent mark on shore. The level of mean sea should also be accurately determined, and, where the rise and fall of tide is so small, I think the mean sea-level would be a better datum than that of low water. The surveys on which I have based my calculations and drawn my plans are rather vague, and but for the extreme simplicity of the natural features of the coast would have been insufficient. I believe, however, that neither design nor estimate can be materially affected by any possible corrections that may be made, but an exact record of the existing state of things is imperative before works which may effect a change in them are commenced.

72. *Conclusion.*—In conclusion, I have only once more to express my acknowledgments of the uniform courtesy with which I have been received by every one with whom I have come in contact in the prosecution of my inquiries and the readiness with which every information and assistance has been afforded to me. If I mention no names it is because I should not know where to stop.

APPENDIX.

Cyclones and other Storms at Madras recorded at the Government Observatory.

1787, 11th November. Centre *North* of Madras.	Wind at noon on 10th, N. Midnight N.-N.-W. 11th, sunrise, N.-W. Noon N.-W. After sunset violent and veering all round the compass. 12th, sunrise, S.-S.-W. Noon S. 13th, sunrise, calm.
1788, 7th May. Centre *North* of Madras.	Sunrise N.-W. Noon N.-W. Midnight N.-W. 8th, sunrise, W. Noon W. Midnight S.-S.-W. 9th. sunrise, S.-S.-W. Noon S.-S.-E. Midnight, calm.
1797, 27th October. Centre at Madras.	Began from northward, veered to N.-E., blew with uncommon violence three hours; about noon suddenly shifted to south, and was almost as violent as before.
1807, 10th December. Centre *South* of Madras.	Began from N., veered to southward of E. and slackened gradually.
1811, 2nd May. Probably central at Madras.	Began from N., blew equally strongly from E.-S.-E. and S., but details not given. Not felt 40 miles from Madras.
1818, 24th October. Central at Madras.	Began northerly, then a lull of half an hour. Then from south with greater fury. The most violent storm then on record.
1820, 30th March. Centre *North* of Madras.	Commenced from N.-E., veered to N., N.-W. and S.-W., but at last quarter gradually slackened. More violent to northward than at Madras.

1820, 9th May. Centre *North* of Madras.	Commenced at N.-W., shifted to W. Worse than storm of October 1818.
1827, 7th May.	Strong wind from S.-E.
8th „	Early morning strong gale from N.-E.
9th „ Centre *North* of Madras.	From sunrise strong gusts from E. to S till 10 A.M. when nearly ceased. At sunset blew from W.-N.-W., and during the night a gale from N.-W. Subsided in the morning of 10th. This storm longer in duration, but not so heavy as preceding ones.
1830, 2nd December. Centre *South* of Madras.	A stormy day, but at Cuddalore, 100 miles south of Madras, a very violent storm.
1836, 30th October. Central at Madras.	Very violent. First from north, then a lull of 30 minutes, then with increased fury from south. Much more severe than those of 1818 and 1820 as shown by barometer.
1841, 16th May. Centre *North* of Madras.	A gale of extraordinary violence. At 9 A.M. N.-N.-E., 10 A.M. to 5 P.M. north. Then for an hour varying from N.-E. to N.-W. At 6·20 P.M. approaching a hurricane from N., at 7 to 7·30 from W. to N. 7·45 south-westerly, a violent gale. 8 to 9, S.-W. to N.-W. and shifting even to S. approaching a hurricane. Thence subsided remaining at S. to S.-W. calm after 7 A.M. on 17th.
1843, 22nd May. Centre *North* of Madras.	N. to N.-W. for 24 hours previous. From 7 A.M. till 1 P.M. continually shifting from N.-W. to S.-W. and back.
1846, 20th October. Centre *North* of Madras.	Began at 11 A.M., wind W.-N.-W., then at 1 P.M. due W., remained between W. and W.-S.-W. till 8 P.M., force increasing to 8lbs.* Then back to W. rising to 13lbs. Then rapidly veered round the compass by E. and S. till at 7 A.M. on 21st, direction S.-S.-W., force 7½lbs. Then gradually fell, direction being S. by W.
1846, 25th November. Centre *South* of Madras.	At 5 P.M. N.-E. force 5lbs. At 7·30 E. by N. pressure 26lbs., then instrument broke. At 7 A.M. calm due S.
1847, 13th October. Pure Northerly gale, not cyclonic.	During the day wind N.-W. and N., for ¼ hour, at 8·45 P.M. changed to E. of N. then remained due N. for the rest of the gale having a maximun force of 12lbs. at 6 A.M. Subsided at 3 P.M., returning N.-W.
1848, 1st November. Light centre *South* of Madras.	Began before sunrise, N.-N.-W. under 5lbs. At 2 P.M. N.-N.-E. At 7·30 N.-E. 6½lbs., at 4½ A.M, on 2nd wind E. and dropped to 1½lbs.
1850, 24th May. Centre *South* of Madras.	At 10 A.M. light at E. by N. increasing till 1·30 P.M., E.-N.-E., maximum at 2 P.M. E.-S.-E. (12lbs.) at 4 P.M. dropped to 5lbs. S.-E. by S.
1851, 4th May. Centre *North* of Madras.	At 11 P.M. (3rd) 5lbs. N.-W. by N. At 3·30 A.M. increasing in force from W. At 5·30 A.M. maximum force 17½lbs., direction W. At 9 A.M. dropped to 10lbs. S.-W., diminishing at S.-S.-W. Calm at S.
1856, 20th November. Centre *North* of Madras.	Began at 4 P.M., direction N.-N.-E. (5lbs.). At 9·30 P.M. N.-E. (8lbs.) steady till 2 A.M. 21st (12lbs.). Then veered northward, maximum force 17lbs. At 4·30 A.M. N. by E. Then back to W. N. dropped to 5lbs. by 9 A.M., direction N.-W.
1864, 18th November. Light centre *South* of Madras.	At 3 P.M. N. by W. (25 miles) steady till 9 P.M. Then veered to N.-E. by N. and N.-E., by 9·45. Continued to increase till at 2 P.M. it was 28 miles per hour, and it dropped from thence as wind veered to the south.
1865, 26th November. Centre *South* of Madras.	Began on 26th at 8 A.M. from N.-E. by N. speed 25 miles, then gradually increasing all day till at 9 P.M. it was N.-E. by E. with speed of 43 miles., Then decreased as it veered to S.-E. by 6 A.M. and thence to south, where it dropped.
1872, 1st May. Centre *South* of Madras.	Wind northerly for two days previously. Blew steadily but with gradually increasing force from N. to N.-N.-E. till midnight. Then increased rapidly up to 8 A.M., being then 53 miles, direction N.-E. By 9·30 veered to E. Then gradually working towards the south, dropping to 14 miles at 8 P.M., and then remaining steady in direction and force from S. to S.-S.-E. for several hours.

* From 1846 to 1856 the force of the wind is given in lbs. on a square foot. Subsequently its velocity is given in miles per hour.

From Robin Allen, Esq., Secretary to the Elder Brethren, Trinity House, to the Under-Secretary of State for India, communicating remarks upon the Madras Harbour Project,—No. 874, dated 23rd April 1874.

I am directed to acknowledge the receipt of Mr. Grant Duff's letter, dated 12th February last, enclosing a Report by Mr. W. Parkes, Civil Engineer, with other papers, on the subject of a projected harbour at Madras, and requesting an expression of the opinion of the Elder Brethren of Mr. Parkes' proposal, and I am to state that the Elder Brethren regret so much time has elapsed since the date of Mr. Grant Duff's letter, but that so many other matters have occupied their attention that they have not been able to give earlier consideration to it. They now direct me to state that the question appears to be one rather for eminent engineers acquainted with foreshores, and the action of the sea and tide thereon, than for the Elder Brethren, but that, so far as their opinion as practical seamen is of value, they have much pleasure in offering the following observations, particularly as many of them are well acquainted with the port from visiting it at all periods of the year, and although some time has elapsed since any of them were there, its peculiarities are fresh in their memories, and they do not gather from the report that any great changes have taken place.

The main point in the report of the engineer is that a close harbour would be preferable to the break-water formerly suggested, upon which I am to state that the opinion of the Elder Brethren would be in favour of the break-water, provided the expense would not be greater than that of making a harbour. It seems to them that a break-water would shelter a larger amount of shipping, and that, if the various quays of the proposed harbour (about 9,000 feet in length) were combined into one as a break-water, with extremities curved inwards towards the shore, a larger and safer area of protection would be given, and that, moreover, there would be the decided advantage of having an opening seaward at both ends, allowing ships to get away by the leeward passage, and that, if placed exactly parallel with the shore, it would probably afford such shelter as would obviate the necessity of ships going to sea without ballast in the face of bad weather coming on, as is now often the case, and give in other respects safe landing for passengers and cargo.

The Elder Brethren are also of opinion that the seaward portion of the harbour, as shown on the plan, would not be free from a dangerous surf outside the entrance, involving considerable risk to vessels entering or leaving, it being well known that at certain periods of the north-east monsoon the actual surf extends a very long way seaward, while, during the prevalence of cyclones, the contemplated elevations would not, as it seems to them, be sufficient to protect vessels inside from the effects of the fury of wind and sea.

In conclusion, I am to state that, although it is a matter which scarcely comes within the scope of Mr. Grant Duff's letter, the Elder Brethren wish me to convey their opinion that the merits of Blackwood's harbour have hardly been sufficiently regarded by the Madras Government in the consideration of this large question. This locality possesses natural advantages over any other part of the coast, which the Elder Brethren believe might be turned to much better account than can result from either of the schemes proposed to be carried out at Madras itself, whilst the construction of a tramway or railway for the transport of goods would obviate the necessity for (and relieve merchants from the apprehension of) the removal of the mercantile establishments from Madras.

In returning the papers as requested, the Elder Brethren wish me to state that they consider the report of the Master Attendant, Mr. Dalrymple, a very fair one, embodying to a great exteat the merits of the question.

From W. Parkes, Esq., to the Under-Secretary of State for India, commenting on the above,—dated 26th May, 1874.

Your letter of the 21st instant encloses, for my information, one from the Elder Brethren of the Trinity House, dated 23rd April, containing their opinion on the nautical aspects of my design for a harbour at Madras.

2. You do not call upon me to submit any remarks upon this communication, but I think it right to take the earliest opportunity of calling attention to the fact that the opinion of the Elder Brethren appears to be based upon a misconception of fact in at least one important point, and I would express the hope that the Secretary of State will take such measures as he may think desirable to prevent the mischief which would otherwise follow the circulation of a conclusion, based on a misconception, emanating from so influential a quarter as the Trinity Board.

3. It is stated that "the opinion of the Elder Brethren would be in favour of the break-water, *provided the expense would not be greater than that of making a harbour.*" They then proceed to describe the advantages which would be secured by a break-water detached from the shore, 9,000 feet in length, and they appear to have assumed that such a break-

water would cost about as much as the harbour I proposed. In that assumption I am unable to concur. The cost of such a break-water would be at least £200,000 greater than that of the harbour, owing to its whole length being in deep water, and to the necessity of constructing enormously strong and very expensive stagings for the conveyance of the large concrete blocks from the shore to the line of the break-water.

4. The length of break-water which could be made for the same cost as the harbour (say £565,000) would certainly not exceed 6,000 feet, and that is the length which had been proposed by the Break-water Committee in 1869, and by Mr. Robertson in 1871, which they estimated respectively to cost £1,062,000 and £1,311,000, the system of construction by "*pierre perdue*" in both cases being much more expensive than that I have proposed.

5. It was this length of 6,000 feet which was the basis of the comparison made in my report; but the addition of 3,000 feet to the length makes all the difference between efficient and inefficient shelter, and I fear that, at the same time, the addition of £200,000 to the cost makes all the difference between a financially practicable and impracticabe scheme. I submit, therefore, that so far my conclusion is not inconsistent with the authoritative nautical opinion of the Elder Brethren, the two having reference respectively to totally different proposals.

6. It must not be concluded, however, that, even if the objection of extra cost were put out of the question, I should recommend the lengthened break-water in preference to the harbour. If there were no other object than to provide smoother water for the anchorage, and the easiest possible communication between the anchorage and the sea, which, from a purely nautical point of view, is the primary object, I should not be disposed to contest the conclusion arrived at by the Elder Brethren, though even on that point the opinions of nautical men are much divided; but when I consider the equally, if not more important, questions of communication between the shipping and the shore, and the facility of providing for extension of trade when necessary, the preference appears to me to be due very decidedly to the harbour, which can be constructed for £200,000, less cost.

7. The Elder Brethren make two comments upon my proposed works, which I think are also based on misapprehensions as to matters of fact. First, that "the seaward portion of the harbour would not be free from a dangerous surf outside the entrance." As to this I can speak with every confidence. There is no surf at that distance from shore, and in that depth of water (7½ fathoms). True, surf has never been seen much beyond the head of the present pier, 1,200 feet from shore, whereas my proposed entrance would be 3,600 feet from shore. During cyclones the crests of the waves are broken by the violence of the wind far out to sea, but this is in itself harmless to shipping.

8. The second objection is that "the contemplated elevations (of the piers) would not be sufficient to protect vessels inside from the effects of the fury of wind and sea." Here, again, I can speak with confidence. The Manora break-water at Kurrachee is relatively about 3 feet lower than the proposed Madras work, and the ordinary monsoon seas to which it is exposed are heavier than those at Madras; yet it is perfectly efficient as a break-water, and I am informed that, at a distance of 100 yards to leeward, the state of the sea is such that ships could lie there without inconvenience during the heaviest weather. It is not proposed to moor them so close as that at Madras. The quantity of water thrown over the piers by the waves would not be materially decreased by their being raised 5 or 6 feet, while, if they were raised to 18 feet above high water, as Mr. Dalrymple suggests, a very considerable amount of water would still be thrown over in heavy seas, and the additional cost would be about £200,000.

In conclusion, I would beg to observe that, since I submitted my report to the Government of Madras, I have taken every opportunity, and I have had many, of consulting with experienced nautical men. Upon two points I have found them so far unanimous, *viz.*, that the break-water, 6,000 feet long, would be quite inefficient, and the harbour efficient, for the purposes required; some (though decidedly the minority) are favourable to the idea of a *long* break-water, but the majority *prefer* the enclosed harbour. There are differences of opinion as to the form, width, and position of the entrance to the latter, and I have carefully considered the several suggestions made, the result of which will probably be that I may submit some slight modification of, or addition to, my design as it stands with the view of meeting the more substantial objections to the present form.

Despatch from the Government of India, to the Secretary of State for India, forwarding certain papers and communicating remarks regarding Mr. Parkes' scheme for a closed Harbour,—No. 118 P. W., dated 17th August, 1874.

We have recently received* from the Government of Madras a copy of Mr. Parkes' detailed estimate (marked private and confidential) of the cost of constructing the proposed harbour at Madras, and

* With a letter dated the 12th June last.

we have the honour now to offer some remarks thereon, and to forward a note prepared by our Secretary in the Public Works Department, after consulting the Financial Department, from which your Lordship will perceive that it is deemed prudent to make considerable additions to the estimate. We also forward herewith all the papers which have not been already submitted to Her Majesty's Government.

2. The advantages of giving protection to the shipping at Madras, and of affording facilities for the landing of goods and passengers, are undeniable, but the scheme involves three questions, which appear to us to demand consideration and discussion before coming to a final conclusion on the subject.

3. There is first the soundness or otherwise of providing a close harbour instead of an open break-water. As your Lordship is aware, there is some difference of opinion on this important point, but it is to be remarked, *first*, that a break-water has been estimated to cost a sum so large that, in the opinion of the Madras Chamber of Commerce, it would be entirely beyond the power of the Port Trust to provide even the interest on the outlay, irrespective of the cost of future maintenance and repairs; and, *secondly*, that, on the whole, the balance of the professional and nautical opinions obtainable is in favour of a close harbour rather than an open break-water. Neither scheme is likely to afford complete, or probably even material, protection from the effect of very severe cyclones, but a close harbour would undoubtedly afford great accommodation to shipping in ordinary bad weather.

4. We believe that considerable uncertainty must always attend conjectures as to the effect of harbour works upon the movement of sand on an open foreshore like that at Madras, but we do not consider that the possibility of the proposed harbour being liable to silt up is a conclusive objection to the projected scheme, unless, indeed, the objection be considered sufficiently strong to negative any attempt to provide shelter for the port of Madras. Your Lordship has the means of consulting higher professional authority than is obtainable in this country, if you should consider it desirable to obtain further opinions on this point.

5. So far as we can form an opinion, we agree with the Government of Madras in recommending Mr. Parkes' scheme of a close harbour as the best that has yet been devised, having regard to all the conditions of the case.

6. The next point for consideration is, whether the details of the mode of construction advocated by Mr. Parkes are satisfactory, and whether the estimates of cost are likely to be sufficient. It is to be observed here that the proposed harbour is to consist of sea walls or break-waters, composed of loose rubble-stone at the base, and of solid concrete blocks resting thereupon, in the same manner as the break-water recently constructed at Kurrachee. We should have been glad had we been able to show from further experience in this country what is the effect of heavy seas and severe storms upon this method of construction, for there is no question but that it will be very severely tested at Madras, but so far as we know there are no grounds for questioning its stability. Here, again, Her Majesty's Government may have better advice available than is at the disposal of this Government.

7. Mr. Parkes' estimate amounts to £565,000, and from a report enclosed it will be seen that the experience obtained from the works at Kurrachee shows that the rates for concrete blocks may be accepted as sufficient, but that some additions should be made to the estimate which raises the probable cost to £710,000; and if interest is to be charged upon this sum during the period of construction, then the amount of capital debt on the completion of the works will rise to £776,465, on the assumption that the time occupied will be four years, and that the advances are evenly distributed. It should also be noted that the scheme projected by Mr. Parkes does not provide accommodation for the landing of cargoes along the sea-walls forming the harbour and that additional outlay on this count will ultimately be required. Cargoes may, however, be landed, meanwhile, at the existing pier.

8. The third and last point for consideration is, how to meet the interest of the money to be lent to the Government of Madras, and provide a sinking fund for extinguishing the capital debt, without causing serious injury to the trade of Madras. The calculations of the estimates of charge and revenue are as follows :—

The Madras Government have taken a payment of 6 per cent. per annum on £600,000 or £36,000, as representing the annual charge for interest and sinking fund, and has proposed to raise the money as follows :—

	£
A rate of 8 annas (1 shilling) per ton on foreign steamers and ships, and four annas (sixpence) a ton on coasting steamers and native craft	20,000
14 annas (1*s.* 9*d.*) per ton on all goods landed and shipped	16,000
TOTAL .	36,000

But it will be seen that higher dues will be required if the cost of the work rises as high as we have thought it prudent to estimate. Taking the calculations given in Colonel Dickens' note, it will be necessary to obtain £42,196 per annum to cover interest at 4½ per cent., and provide for the re-payment of capital in 40 years. To this we add £10,650 per annum, on the average, taking one year with another, for repairs and maintenance, and £4,000 for the port charges as at present. The result is that a sum of £56,846 is required to be provided annually.

The following are the very highest dues we can expect to be paid, calculated on the existing trade:—

	£
440,000 tons of shipping, at 8 annas, or 1 shilling per ton	22,000
220,000 „ of goods. at R 1½, or 3 shillings „	33,000
TOTAL .	55,000

9. We consider that the nature of the trade at Madras makes it evident that from steamers calling at the port, but a very moderate amount can be levied without running serious risk of driving them away altogether, and we agree with the Madras Government that the returns from tonnage dues cannot well be taken at a higher figure than £20,000 a year, leaving £36,846 to be annually provided for by a charge upon the goods landed in such manner as the Government of Madras, after further consultation with the Government of India, may consider proper.

10. We think it desirable to record our opinion that, if this loan be granted, there cannot fail to be considerable risk of loss to the revenues of India, both on account of the uncertainty of all harbour works, and also on account of the probability of pressure being put upon the Government of India to relieve the trade of Madras from the burden of paying the interest if the harbour does not prove to be a success, or if the port-dues operate injuriously, and it is for Her Majesty's Government to consider whether these risks are, or are not, counterbalanced by the undoubted advantages that will accrue should the undertaking prove to be a successful one.

11. The Governor of Madras in Council having expressed his anxiety that the subject of this harbour should be referred for the decision of Her Majesty's Government with as little delay as possible, we have not waited to communicate our opinions to the Government of Madras, but have sent a copy of this Despatch, and requested that Government to communicate direct to your Lordship any observations or explanations which they desire to make.

Note by Secretary, Government of India, in the Public Works Department, on Mr. Parkes' design and referred to in above despatch.

1. Mr. Parkes' estimate amounts to £565,078.

2. The Madras Committee recommend an addition for rubble work, of £20,000.

3. The rate for concrete blocks has been tested by the rates of work at Kurrachee, and seems ample.

4. Mr. Parkes' estimate allows 10 per cent. for contingencies, which, I presume, is meant to cover cost of repairs from ordinary wear and tear and from storm damages while under construction. I think it would be only prudent to allow this 10 per cent. to stand for the contingencies of construction only, and to add 10 per cent. more, or a round sum of £50,000, for repairs of damages while under construction.

5. Next, there is an allowance of only 5 per cent. for superintendence. This might suffice if a contractor could be got to take the work at a lump sum contract on the estimate. But if the work is to be done departmentally as at Kurrachee, though there may be a saving on the rates of work, there will certainly be excess in supervising establishment. The rate for executive establishment at Kurrachee has been on the average 13·8 per cent. on the cost of work done. To this has to be added the cost of auditing the accounts and the general direction to the work, afforded by the superior officers of the department, and, besides this, there are the payments to Mr. Parkes for professional advice prior to and during construction. On the whole, I do not think it will be safe to take the total cost of supervising establishment at less than 20 per cent., or, say, £75,000 in excess of Mr. Parkes' estimate.

6. Thus, the total of the estimate may be taken at—

	£
Mr. Parkes' original sum	565,078
Add for rubble work extra	20,000
„ for repair of damages during construction	50,000
„ for supervising establishment	74,922
TOTAL . . .	710,000

This may, I think, be considered an outside estimate.

7. But there is an addition yet to be made, namely, for interest during construction, as increased harbour dues cannot be collected till the trade begins to reap the benefit of the works.

Thus we shall have—

	£
First year's expenditure	177,500
Interest at 4½ per cent. (taken for half the year on average)	3,993
Loan at end of first year	181,493
Add second year's expenditure	177,500
	358,993
Interest at 4½ per cent.	12,161
Loan at end of second year	371,154
Add expenditure third year	177,500
	548,654
Interest on this	20,696
Loan at end of third year	569,350
Add expenditure in fourth year	177,500
	746,850
Interest	29,615
Loan at end of fourth year	776,465

Thereafter the interest will be £34,941; but making arrangements to pay off the debt by equal instalments, including interest in 40 years, the annual payment should be £42,196. To this again has to be added the cost of repairs and maintenance, which, on the average, may perhaps be assumed at 1½ per cent. on the estimate of £710,000 = £10,650. Further the present cost of the port establishment must be added, £4,000. Altogether, then, the payment of £56,846 per annum should be looked for to make the project safe.

8. This is a much larger sum than has been provided for in the Madras estimates, and it will be necessary to raise higher dues accordingly. In round numbers the trade of the port may be taken at 440,000 tons of shipping, and 220,000 tons of goods. If the port dues be taken at 8 annas (1 shilling) per ton on the former, and R1½ (3 shillings) per ton on the latter, the result would be—

	£
440,000 tons of shipping, at 8 annas, or 1 shilling	22,000
220,000 „ of goods, at R1½, or 3 shillings	33,000
TOTAL	55,000

The Chamber of Commerce would reduce the ship tonnage for the coasting trade to half the sum, making the total revenue from tonnage of shipping £20,000.

But the rate of R1½ a ton on goods is high. At Bombay the limit is R1¼; and as the harbour at Madras will admit of ships loading and unloading at the pier, this may be considered to be a reasonable rate according to Bombay experience. The R1½ rate is, perhaps, admissible being 20 per cent. only in addition to the Bombay rate.

9. If the extinction of the debt were not looked for, but only interest and repairs, the charges to be met would be—

	£
Interest	34,941
Repairs	10,650
Port expenses	4,000
TOTAL	49,591
And the rates of dues might be fixed on shipping as proposed by the Chamber of Commerce	20,000
On goods at a trifle above the Bombay rate, namely, 1⅜ instead of R 1¼ per ton	30,250
TOTAL	50,250

In both these and the former calculations it is presumed that there will be no increase in port establishment, except for the maintenance and repairs of the harbour works.

10. Considering the high estimate taken for the works, and the results of the calculations of the two last paragraphs, with the facts that the harbour may increase the resort of shipping

to the port, and that the object in view is worth some risk, perhaps the Government of India may be justified in advising the Secretary of State to grant the loan; if on further professional examination in England the project and estimate be accepted as good.

11. I will only add a suggestion that the duty on goods should be by weight, and not by boat load. Landing at the pier is essential to the realization of the duty on goods; and the inconvenience of weighing is easily got over by the use of weigh-bridges.

Despatch from the Secretary of State for India, to the Government of India, communicating sanction to Mr. Parkes' scheme for a harbour at Madras, dated 11th March 1875.

No. 36, dated 16th December 1873.
" 1, " 9th January 1874.
" 7, " 12th February "
" 23, " 29th June "
" 26, " 13th July "
" 32, " 14th September "

I have considered in Council your Excellency's Despatches Nos. 4 and 118, dated 8th January and 17th August 1874, referring to the proposed harbour at Madras, together with the Despatches of the Madras Government of the numbers and dates noted on the margin relating to the same subject.

2. In accordance with the suggestions of your Excellency's Government, I have caused Mr. Parkes' plans to be submitted for consideration to J. F. Bateman, Esq., C.E. Mr. Bateman has been asked to give his opinion in reference to the three points raised in your Despatch No. 118, dated 17th August 1874. The following questions were put to him :—

1st.—Whether the proposed method of constructing the break-waters, as described in the Report dated 4th November 1873, affords promise of stability.

2nd.—Whether the obstruction to the littoral currents offered by the break-water is likely to cause an accumulation of sand; and, if so, within what period such accumulation is likely to impede the entrance to the harbour?

3rd.—Whether the proposed harbour, being enclosed by break-waters, only 3 feet 6 inches above high-water mark, and having an opening 150 yards wide exposed to the sea, would afford sufficient protection to the shipping moored within it during the prevalence of high winds blowing inshore.

3. Upon all these points Mr. Bateman's answer, as your Excellency will see from the enclosed report,* is in accordance with the opinion of Mr. Parkes. The Madras Government are also confident in the soundness of his proposals; nor do I understand you to feel any hesitation in acceding to their view, except upon the points which you wished to be submitted to the examination of an English engineer.

* Dated 3rd December 1874.

4. Considering these favourable judgments in conjunction with the experience of Mr. Parkes' mode of construction which has been furnished by the harbour of Kurrachee, I am satisfied that his plans are likely to be suitable for their purpose, and may be safely sanctioned.

5. The question of expense is, as might be expected, a matter of some controversy. Your Government is disposed to place it at as high as £776,465 ; Mr. Parkes' own original estimate did not exceed the sum of £565,000. The Madras Government have adopted an intermediate view, and are of opinion that £628,000 will be amply sufficient. A similar discrepancy exists with respect to the estimate for maintenance, which is placed by your Government and that of Madras at the sums of £10,000 and of £2,000 a year respectively.

6. The contingencies upon which the cost of constructing and repairing a harbour depends are so uncertain that it would be hazardous to express a confident opinion in respect to these conflicting estimates. But the question is too large to be dealt with only upon financial grounds. Many human lives are sacrificed in the tempests which annually ravage the Coromandel Coast, and it is probable that a large proportion of these might be saved if the vessels which are now surprised in the roadstead could seek the shelter of a harbour. The material interests of the vast population that inhabits the Presidency of Madras are not less deeply affected by the unsheltered condition of the port. It can hardly be doubted that, if a safe and regular access to the sea could be secured to them, their industry and trade would be greatly stimulated. The public utility of a harbour can seldom be measured by the actual return in the shape of dues which it can be made to pay, and in the Presidency of Madras, where the destitution of shelter upon the seaboard is so remarkable, such a principle of valuation would be specially misleading.

7. I do not, therefore, propose to make the construction of the harbour of Madras depend upon the accuracy of the estimates submitted by the Government of Madras. Those estimates may, however, properly serve as a guide in determining the sum which is to be advanced for the work out of the Extraordinary Public Works Fund. The principles upon which that Fund was constituted, and of which I reminded you in my Financial Despatch of the 23rd July 1874, No. 387, forbid its application to any work except so far as the yield of that work is likely to repay the interest upon its cost.

8. Looking to the tonnage both of the ships which visit the port and of the goods which pass through it, and also to the burdens which are borne without injury to the trade of other ports, I am disposed to concur with the opinion of the Government of Madras, that dues raised upon shipping and upon goods in that port may be trusted to repay interest upon the £628,000 which they estimate as the outlay necessary in addition to the annual sum which, in their opinion, they will have to provide for the maintenance and working expenses of the harbour. I do not conceal from myself that circumstances now unforeseen may render inevitable an excess either upon the capital outlay or the annual expenditure in maintenance. But the Imperial character of the undertaking, and the high interests involved in it, do not permit me to look upon the existence of that contingency as an insuperable obstacle to the prosecution of the work. If the excess should arise, it must be borne upon the ordinary budget; but until the probability of its being incurred is ascertained, the necessity for providing for it will not arise. I desire, however, to record the opinion that, if the full amount of the highest estimate formed by your Government should be reached, the expenditure will still have fallen short of the benefits which the work may be confidently expected to confer upon the people of Madras.

9. I have, therefore, in conclusion, to request that the Government of Madras may be directed to introduce Bills into the Legislature providing for the levy of dues, either on shipping or on goods in the port of Madras, upon the construction of a harbour there, which will be sufficient to defray interest at 4 per cent. of a loan of £628,000, and a yearly expenditure of £6,000; and, further, that your Excellency's Government will, on the passing of those measures, advance the sum of £628,000 out of Extraordinary Funds to the Government of Madras for the construction of a harbour in accordance with the plans of Mr. Parkes, and under his superintendence.

Report by J. F. BATEMAN, Esq., C.E, on Mr. Parkes' design and referred to in above despatch,—dated 3rd December 1874.

I have the honour to answer the questions submitted to me by direction of the Secretary of State for India in Council on the important subject of the proposed harbour for Madras designed by Mr. Parkes.

I have given it my most careful consideration, and have had the advantage of obtaining from Mr. Parkes, to whom I was referred, all the information which appeared to me desirable, and of much of which, especially of a local character, I was necessarily ignorant. I have also obtained from him full particulars of the break-water at Kurrachee, and the nature and extent of injuries which it received during its construction and during the two following monsoons. This information is most valuable, as bearing directly upon the question now under consideration, as the proposed mode of constructing the break-water piers at Madras is the same in principle and to a great extent the same in design.

On the important point of the stability of such a work, I have also brought into consideration and under review all the circumstances of break-waters, either similar or dissimilar in their construction, with the object of well weighing the proposal of Mr. Parkes before I ventured to incur the responsibility of either approval or disapproval.

The expression of my opinion is strictly limited to the three questions submitted, and as the most convenient form of answering them, I have arranged the questions and answers in the following parallel columns :—

Questions.	*Answers.*
1. Whether the proposed method of constructing the break-water, as described in the Report dated the 4th November 1873, affords promise of stability.	1. I am of opinion, after the full information I have received of the mode of construction adopted at Kurrachee and the success and stability of the break-water there, exposed, as it is alleged to be, to as heavy or a heavier sea than the break-water at Madras can be, that the mode of constructing the break-water, as described in Mr. Parkes' report of 4th November 1873, does afford promise of stability. It is, however, very probable that, both during construction and subsequent to completion, very severe storms may disturb and injure the work; but this contingency is not, in my opinion, sufficient to prevent the execution of the break-waters in the manner proposed by Mr. Parkes.

2. Whether the obstruction to the littoral currents offered by the break-water is likely to cause an accumulation of sand; and, if so, within what period such accumulation is likely to impede the entrance to the harbour.

2. A break-water or pier projecting at right-angles from the coast must of necessity obstruct littoral currents and arrest travelling sand or shingle, but I have no information as to the quantity of sand which would be thus arrested in a year, and cannot therefore make any calculation of the period within which the accumulation would extend as far out as the points of the piers, or impede the entrance to the channel.

The piers or sides of the enclosed harbour are proposed to be extended nearly two-thirds of a mile from shore, and I am of opinion that, whatever may be the quantity of sand which will be arrested, a very long period will elapse before the accumulation behind the walls can have an injurious effect, so long, indeed, that it may be disregarded.

3. Whether the proposed harbour, being enclosed by break-waters only 3 feet 6 inches above high-water mark, and having an opening 150 yards wide exposed to the sea, would afford sufficient protection to the shipping moored within it during the prevalence of high winds blowing inshore.

3. The break-water, though the top be only 3 feet 6 inches above high-water, will very effectually stop the progress of driving waves, and will afford material shelter within the harbour. It will not prevent water rolling over in heavy seas, but the destructive effect of such water will be destroyed, and no injurious wave can be propagated within the space of the harbour.

I consider an opening of 150 yards will afford easy ingress and egress to vessels, and that any waves entering this space from high winds blowing inshore will, as soon as they have entered, spread out in all directions with such rapidity as to be wholly dissipated as objectionable waves within a short distance of the entrance.

The water within the harbour in all winds, however high, will be comparatively quiet.

Despatch from the Government of India, to the Secretary of State for India, intimating delay in introduction of Madras Enhanced Rates of Harbour Dues Bills owing to doubts as to practicability of constructing an efficient Harbour on plans now under consideration,—No. 133 P. W., dated 15th December 1877.

With reference to your Lordship's Despatch No. 32 (Legislative), dated 17th May last, on the subject of the Madras Harbour Works, we have the honour to report that, with the concurrence of His Grace the Governor, we have arranged that our colleague Sir A. Clarke should shortly visit Madras, and examine the works in progress in connection with the harbour, and thereafter advise us as to the course that should be eventually pursued.

2. In the meantime, and in view to prepare the way for the examination above spoken of, we have sent to Madras an experienced officer of Royal Engineers who has been charged with the duty of collecting certain information and conducting certain observations in accordance with instructions which have been issued to him by our Hon'ble colleague, but who will in no way advise the Local Government, or interfere with the works that may be in progress.

3. Pending the receipt of the information in question, we have deemed it advisable that the Bill "to enhance the rates of dues leviable on vessels entering the Port of Madras," which Sir Alexander Arbuthnot obtained leave to introduce on the 14th September last year, should not be proceeded with. The introduction of this Bill has been delayed hitherto owing to doubts which have been raised as to the practicability of constructing an efficient harbour at Madras upon the plan upon which the works now in progress are being constructed.

Report by W. Parkes, Esq., M. Inst. C. E., Chief Engineer, Madras Harbour Works, on the progress of the Madras Harbour Works, for the quarter ending 30th June 1878,—dated 27th August 1878.

I have the honour to forward you a plan showing the progress of the above works in the quarter ending 30th June last, and two photographs of the north and south piers respectively, taken from the head of the screw pile pier on the 6th July.

2. There had been, up to the 30th June, an advance of 76 feet at the north pier and 34 feet at the south, and the whole of this advance had been made in the month of June. In the following month of July the north pier advanced a further 113 feet, and the south pier 43 feet, showing that the rate of progress was continuing, even during the unfavourable season of the south-west monsoon. I shall refer to the difference in the progress of the two piers further on.

3. In my last quarterly report (paras. 8—11) I mentioned that block-setting had been suspended after the 1st of April to give the blocks more time to harden. It was not resumed till the last day of May.

4. This suspension of the work during the most favourable season was a very serious matter, as, besides the evil of the delay itself, it seemed to imply either a fault in the original arrangements of the work or a miscarriage of those arrangements. Mr. Thorowgood was himself absent on account of illness from the 18th March to 18th May, so that he was not personally responsible for the suspension, and was able on his return to form an unbiassed judgment as to its necessity.

5. I may repeat that the area of the block ground was originally calculated to hold the full number of blocks which could be set at the most favourable season in the time necessary for new blocks to harden. The calculation was based on the experience of the similar work at Kurrachee, and I think that to have made a large provision in the first instance would have been an unjustifiable expense.

6. The result of Mr. Thorowgood's investigation is, however, that, for some reason not yet fully known, the concrete does not harden quite so quickly at Madras as it did at Kurrachee, and also that, as the sea is never so quiet at Madras as it was during the short working season at Kurrachee, the blocks are subjected to heavier blows and strains while being set, and consequently require greater strength. Two or three blocks were actually broken, but not to a serious extent.

7. From these two considerations combined, neither of which could have been taken into the original calculation of the number of blocks required to be kept in stock, Mr. Thorowgood is of opinion that a delay of two or three weeks would have been justifiable, but that so long as six weeks, which was extended to two months by rough weather in the latter part of May, was unnecessary.

8. The delay appears to have been strongly urged by Mr. Lowe, the principal foreman. If Mr. Thorowgood had been himself on the spot, he would, no doubt, have overruled Mr. Lowe, but I am not surprised that Mr. Beardmore, while only in temporary charge, did not feel justified in doing so. It is to be regretted, however, that Mr. Beardmore did not report the facts either to Mr. Thorowgood or to myself more fully, and at an earlier date. Had he done so, either of us would have taken the responsibility of authorising the resumption of work.

9. Experiments are now being made with the view of determining more definitely at what age the blocks may be safely used, and at the same time, with a view to avoiding the possibility of a similar delay in the next favourable season, Mr. Thorowgood has applied for sanction to form a supplementary block ground near the south pier. On this either new blocks may be made by hand labour and used when the stock of machine-made blocks of the proper age at the present block ground is exhausted, or the machine-made blocks may be stacked upon it when hard enough to be removed, but not hard enough to be lowered into the sea. The existing block grounds have also been slightly lengthened at each end, as shown in red on the plan.

10. During the two months that block-setting was suspended, considerable progress was made at both piers in the formation of the rubble bases in advance. The extent to which stone had been deposited up to 30th June is shown on the plan. This stone was carried out mainly by Masula boats from the shore. The Masula boats answer very well for the present, and the work is done at almost exactly the cost I estimated, but as the work advances into deeper water the quantity of stone required for filling up to the level of the foundation of the concrete blocks will be greater, and a greater speed of work than is possible with the Masula boats will be required to keep ahead of the block-setting.

11. For this purpose the steam hopper barges which have been so long waiting are now being brought into action. The use of the Masula boats to a greater extent than I originally anticipated has rendered unnecessary the construction of a timber jetty for the hopper barges to lie alongside of to receive their cargoes of stone. The side of the north pier itself is now available for this purpose, and thus much of the expense originally anticipated for the jetty has been saved. There are, however, still some practical difficulties on account of the

strong run of the sea along the solid face of the pier even on the lee side, but I have no doubt means will soon be found to overcome these.

12. I now come to the ever-recurring sand question. It will be seen from an inspection of the plan that there has been since 31st March to the southward of the south pier an accumulation forming a triangle of 350 feet along the pier, and of 2,000 feet along the coast. Although the present is not a favourable time for drawing any definite conclusions as to the effect of future accumulations, which will be better deferred till the close of the north-east monsoon, yet the lines laid down from actual survey are so clearly illustrative of the principle on which my previous anticipations have been based, that I think I may usefully call attention to them.

13. The triangle in question may be taken to represent approximately the accumulation for the whole year, as both in 1876 and 1877 it was found that the north-east monsoon removed all the accumulation which had taken place since June. Taking this triangle, therefore, as our unit of quantity for a year's accumulation, each succeeding year may be expected to add an equal quantity in the form of a parallel strip on the hypothenuse of the triangle, which will be longer and deeper, but proportionally narrower, every year. Ultimately the triangle will extend from some point near the bend of the pier (say, where it crosses the seven-fathom line) to a point a proportionate distance along the shore to the southward. As this triangle will have its side along the pier seven times the length of the corresponding side of the present triangle, its length along the coast also seven times that of the present triangle, while the maximum depth of sand will be 7 fathoms, instead of 2 fathoms, it will be seen that the time necessary for its formation must be well in excess of the hundred years which I have already put forward as the probable period for which the south pier will act as an effectual protection to the harbour. Yet, I think, the advance of the sand must have had a more menacing appearance to local observers this year than on either of the former years at the same period.

14. On comparing the present coast line between the piers with those of 31st March 1878 and of 30th June 1877, it will be seen that there has been no advance. Last year it will be remembered there was an advance between March and June, which I attributed to the length of the south pier being insufficient to prevent the passage of sand round its end. It is now obviously quite effectual for this purpose, and the next few months' advance of the pier will, I hope, put a final stop to any anxiety as to future encroachment on the water space of the harbour. The width of beach which has been gained, however, appears to be already fully occupied for the purposes of trade. As the piers give more shelter, the travelling of the sand northward and southward according to the monsoon will be lessened, and the line of shore will become more permanent, and therefore still more useful.

15. The coast to the northward of the north pier continues to waste during the prevalence of southerly winds, and the waste is regained in northerly winds. The effects of these fluctuations are not very serious, but when their possible extent has been more clearly determined by experience, it may be desirable to adopt some permanent measures of protection.

16. I now come to the movements of the sand near the ends of the piers. Similar movements caused so much trouble and delay last year that in the nine months from April to December the north pier could only be advanced 60 feet. This year, in two months (June and July), the north pier has advanced 189 feet, and the south pier 77 feet. The inferior progress of the latter, however, is due to the same cause as affected the north pier last year, *viz.*, the accumulation of sand over the rubble base in front on the blocks.

17. The contour lines of depth on the plan show generally the state of the bottom in February of this year. The soundings in figures are the depths found by Mr. Beardmore at the end of June and the beginning of July. It is a very difficult matter to get soundings at all in such a situation, and such as there are must have been obtained by the exhibition of great promptitude and at some risk. It is, therefore, no reflection on Mr. Beardmore to say that they are insufficient to give anything like a complete idea of the form and extent of the accumulation. Still less would they justify any definite conclusion as to the cause of it. We must still rely upon theoretical considerations as the main basis of our anticipations for the future, though we may usefully test the correctness of our theories by comparison with such a partial collection of facts as we have obtained.

18. It will be seen that upon the line which was the 4-fathom (or 24 feet) contour in February there is now off the end of the south pier a shoal with a least depth of 8 feet, showing an accumulation of 16 feet. This is very similar to the accumulation which was formed off the end of the north pier last year, when that was in a position relatively to the depth of water and the coast line, very similar to that of the south pier at present. Now, the end

FIG. 1.

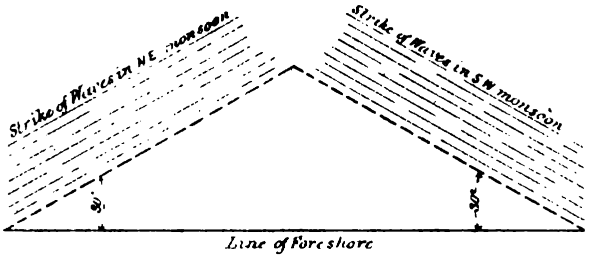


FIG. 2

FIG. 7

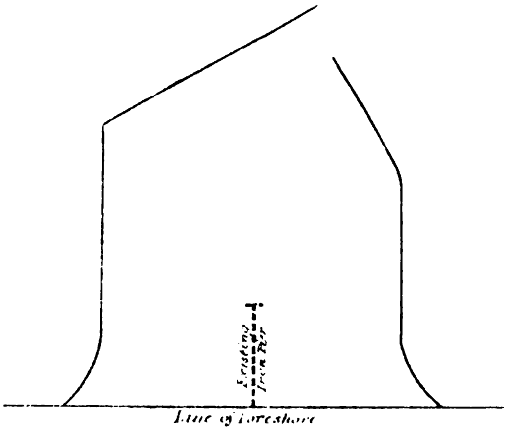


FIG. 8

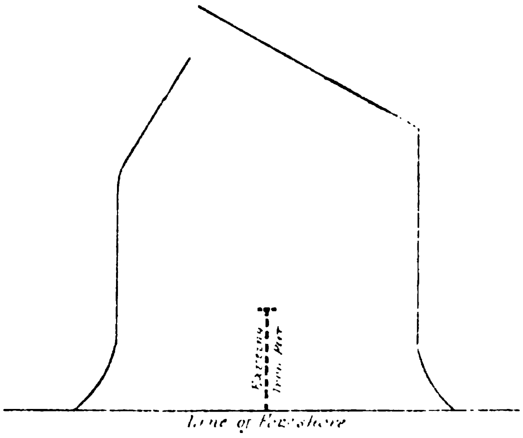


FIG. 13

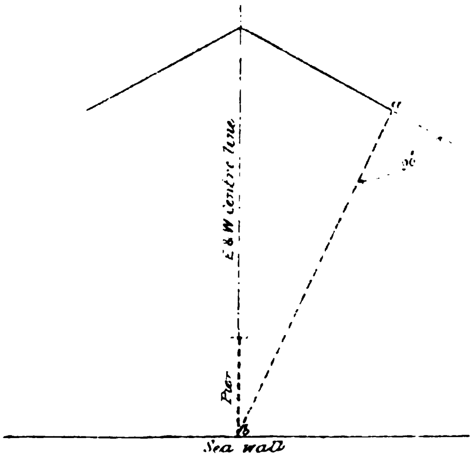
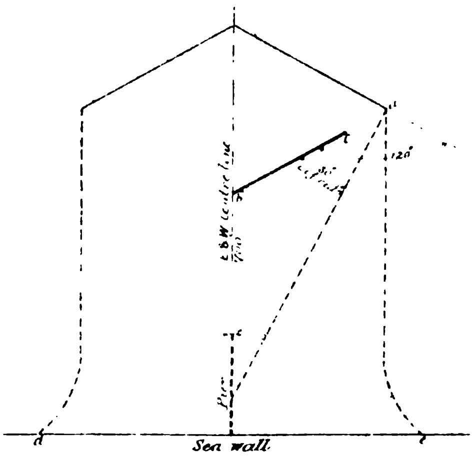
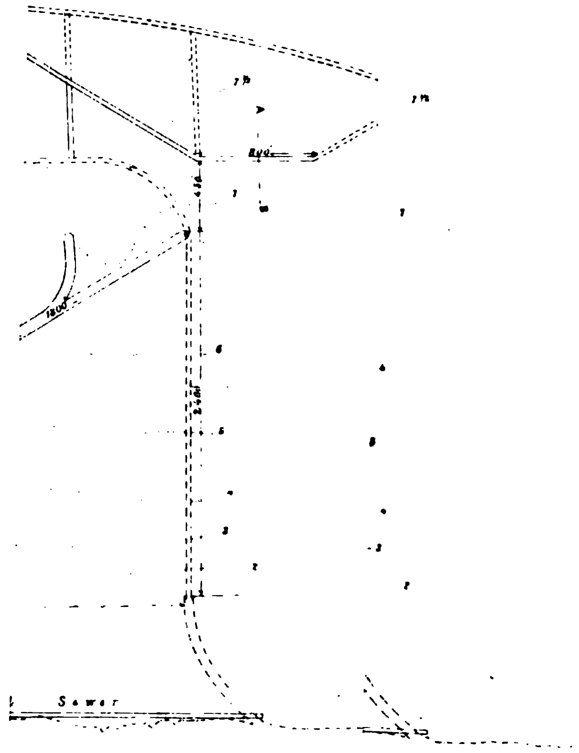


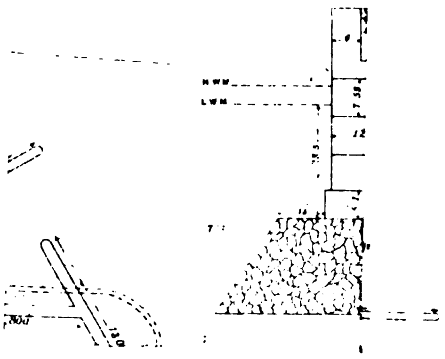
FIG. 14



PLANS

	No. 1 A	No. 1 B
	Rupees	
	137.77.[illegible]	14[illegible].29.[illegible]
	Ships.	
...ine	8	8
	8	16
...ns		
	12	20





of the north pier is perfectly free of sand, and it will be seen that the depths north and south of it in the three lines of soundings differ little from the depth shown by the February contours.

19. This marked contrast in the state of the sand near the ends of the two piers is, so far, a literal fulfilment of the anticipation I ventured to express, that the good advance of the north pier made in the early part of the year would have carried it past any future sand difficulty. There are yet two or three months before the change to northerly winds may be expected to introduce a change of conditions as regards the movement of sand, but it is hardly likely that any serious accumulation will now take place.

20. The question now arises whether we may anticipate that the advance of the south pier before the next south-west monsoon will carry it into a position as favourable as that in which the north pier now is. I can see no reason to doubt it. The conditions required are a greater depth of water and a greater distance from the broken-water which fringes the beach. It may be suggested that the fact of the advance of the beach along the north pier having been arrested, while that at the south pier will continue, will make a difference to the disadvantage of the latter, but the pier will advance much more rapidly than the beach, and if the interval between the end of the pier and the beach is sufficient, the advance of the beach cannot affect the movement of the sand near the head of the pier.

21. I have previously expressed an opinion that the advance of the line of beach, and the accumulation of sand at the pier end, are due to two distinct causes, the one being an alongshore movement of the sand, the other a movement in the direction of the waves, originally obliquely transverse to the line of shore, but diverted and confused by the abrupt obstruction of the pier. The form of the bottom, as shown by the soundings near the south pier, is more consistent with this theory than any other. There is an accumulation of 16 feet on the 2-fathom line close to the pier, and there is an accumulation of 16 feet to the N.-E. of the end of the pier on the 4-fathom line, but between the two, on the 3-fathom line, the accumulation is only 9 feet. These two maxima of accumulation, with a minimum between, can hardly be due to a single cause. It is more probable that if the two maxima had been at a greater distance apart, the two banks would have appeared quite independent of one another, with an interval between, in which there would be no accumulation.

22. On the whole, I think I am justified in representing the present state of the works as very encouraging. In June and July 1877 the north pier advanced only 14 feet. The difficulties of sand, breaking seas, and uncertain weather, were then at their height. In June and July this year, at the south pier, with the same difficulties, but with better knowledge of how to meet them, the advance has been 77 feet, while at the north pier, with the difficulties of sand and breaking seas left behind, but with presumably the same conditions of uncertain weather, the advance has been 189 feet. This is more than I anticipated at this season, but I take it as a confirmation of the belief I have always entertained that the most formidable difficulties of this work would be encountered before we reached the 4-fathom line. I think it is also a proof of the energy displayed by the executive staff under very trying circumstances.

23. The season has been remarkably unfavourable, the heat having been extreme, and it must be remembered that the European members of the staff are men who, having gained their special experience in England, have gone to India at a later age than is usual. I regret to say that the effect has been felt. Mr. Thorowgood was absent for two months from illness, and has again suffered; since his return Mr. Beardmore was also obliged to take a short leave of absence from the same cause, and a still greater misfortune has occurred in the death, from abscess of the liver, on the 19th July, of Mr. John Chicken, the Foreman Mechanic, a very valuable member of the staff. His place will be supplied by promotions among the subordinates of his department.

24. I would request that a copy of this report be forwarded to the Government of Madras for their information.

Minute by the HON'BLE SIR A. CLARKE, on the Madras Harbour Works.

When on tour in the Madras Presidency in February 1878 I had two opportunities, with an interval of a little more than a week between, of thoroughly inspecting the Madras Harbour works. This interval was so far important as it afforded scope for further observations to be taken of the foreshore, which observations tended to prove that the period was one of quiescence as regarded the sand ordinarily in motion. The north-east monsoon had done its utmost towards smoothing down the irregularities in the coast line, caused by the sand brought up and piled, as it were, against the projecting piers of the harbour by the previous south-west mon-

soon. The coast line had, in fact, assumed the most favourable aspect that it is likely to assume, and was then advanced about 250 feet from its original position.

2. The rate of progress of the work so far might be considered satisfactory, considering the many difficulties which had been faced. The north pier blocks had advanced 135 feet from the point at which they start from the curved rubble approach, and the south pier 173 feet. As regards the accumulation of sand within the harbour, it is a matter of regret that the relative rates of progress of the two piers are not reversed, as it is the advance of sand from the south, and not the north, that is to be dreaded.

3. During the last south-west monsoon considerable erosion of the foreshore had taken place north of the harbour works, and I learn that even in the south-west monsoon just concluded, this evil has been considerably extended, to the injury of the coast road at this point. This is, however, capable of temporary remedy by means of groynes, and is receiving attention, but, in my opinion, a sea wall (the details of which will require careful thought) will be found necessary as a permanent measure.

4. Between the two piers of the harbour no less than eleven sewers of different sizes debouch. Some of these are in constant operation, others intermittent; and, as there is always more or less difficulty in keeping clear some of the openings in consequence of the shifting character of the beach at this point, the result is most unsanitary. This is an evil which will require prompt attention, and I have had prepared estimates for an intercepting sewer, which are now to hand.* This sewer will lie within a concrete sea wall which it will be necessary to construct between the two piers of the harbour; and as it will diminish, rather than increase, the cost of the wall, it will not entail any extra cost to the town. It being an absolutely necessary adjunct, I must consider it as pertaining to the project, though not entertained in the original estimates.

* *Vide* Appendix III.

5. I carefully inspected all the arrangements for the manufacture of the concrete blocks, &c.; and I need make no further comment on this portion of the works than to remark that it has been carefully designed and executed. More space for the collection of manufactured blocks, had it been available, would certainly have been advantageous.

6. Want of rolling-stock had been a serious hindrance to the more rapid progress of the works; but this has been an unavoidable evil, due to the exigencies of the famine, and will, I trust, have been overcome ere this. The importance of this deficiency of rolling-stock becomes evident when the sources of the stone, of which such large quantities are required, are considered. These are—

1st.—Trittany, which gives granite at R2-0-6 per ton in the yard; but it is 51 miles distant on the north-west line, and has been abandoned as being too far off.

2nd.—Chinamapett, 36 miles distant, on the same line, the produce of which quarry is quartz, delivered in the yard at R1-6-3 per ton. This, however, is found to be too hard for the stone-breakers, and will be discontinued after what is ready (about 5,000 tons) has been used up.

3rd.—Ambatoor, 9 miles distant, and on the same line of rail. It yields laterite, which costs R1-2 per ton in Madras. This laterite is being used exclusively for the north pier, as base, for protection of foreshore, for surf bank, and partly for concrete blocks.

4th.—Palaveram, 12 miles out on the South Indian line, which gives three kinds of stone, *viz.*—(*i*) large boulders up to 7 cwt. for foreshore, delivered at R1-1 per ton; (*ii*) chips of granite, at R1-2, used for concrete blocks and for completing levelling up of the base in both piers; (*iii*) small crushed granite for concrete blocks at R1-6 per ton.

5th.—On the South Indian line, and 15 miles from Madras, a quarry which yields stone of all kinds, at R1-1 per ton.

7. The cement used in the concrete blocks was at first Portland cement procured from England, of which a large stock was still in hand and being used up, but excellent cement quite coming up to the English standard, and manufactured from materials on the spot, will in future be chiefly used. This cement is the product of works started by General Morgan not far from the Harbour works-yard. It is made from blue clay and sea-shells, and is some R5 or 6 per ton cheaper than Portland. The shells, which, to secure good cement, must, it is stated by the manufacturers, be ground unburnt, are so much harder than the chalk used in the manufacture of Portland cement, as considerably to enhance the cost of the Madras cement; but in many respects the Madras process is so open to further improvements leading to economy that a hope is justifiable that the cost will ere long be considerably reduced.

8. The general design of Mr. Parkes' harbour is one of which, from my first knowledge of it, I have never disguised my disapproval. It was, however, sanctioned and commenced

previous to my arrival in this country, and under such circumstances I did not feel myself justified in hastily condemning the work on other grounds than the theoretical ones which had already been advanced, and which required time to test their value; but the tenor of the progress reports reaching me from time to time appeared to so great an extent to afford ground for the fears that had been expressed as to its ultimate success, that I considered it imperative on me to visit the works and judge for myself. My time in Madras would necessarily be short, and consequently, with the consent of His Excellency the Viceroy, I deputed Lieutenant-Colonel Thomason, R.E., to proceed to Madras in December 1877, and collect for me certain data which I considered necessary to arrive at a just conclusion; the time intervening between that Officer's and my own arrival in Madras was therefore occupied by him in obtaining sections through the surf borings to ascertain the strata underlying the harbour site, and in collecting information affecting the financial aspects of the question.

9. When I left Madras, my opinion was that in the existing state of the works there was not sufficient ground for stopping further expenditure on a project which, though faulty in itself, might still admit of modification to such an extent as to eventuate in a useful work. More information was necessary as to the effect of the works at a more advanced stage, as well as regarding the probable cost of any modifications which might be necessary. To obtain this, Colonel Thomason again proceeded to Madras during the south-west monsoon, and it is on the aspect of affairs as then presented to him, together with our previous experience, that I now venture on a more definite opinion than it was in my power to give after my visit.

10. From an engineering point of view, by far the most serious difficulty besetting the present project is that occasioned by the travelling sand. Of this Mr. Parkes, in his report dated Madras, November 4th, 1873, makes light in such an unaccountable way that it seems only necessary to quote the basis of his original calculations to show how very markably the progress of his works since then has shown their unreliability.

11. In paragraph 15 of his report Mr. Parkes says:—

"I might quote many instances of groynes, piers, and other obstructions carried out from sandy beaches similar to that at Madras, in which the rate of advance has been rapid at first, but in a few years so slow as to place the ultimate extension of the sand to the head of the obstacle in so distant a future as to render it practically no element in the question."

Taking as special illustrations of harbours on travelling beaches, if we take those on the south coast of England, which are in a degree only similar to Madras as regards the travelling of the beach, we find that they point to a conclusion so different to that arrived at by Mr. Parkes, that the *onus probandi* of what he states in general terms surely in such an argument rests with him, and not with his critics. The coast of England has the advantage of a rise of tide compared with which that of Madras is quite insignificant. It is only by force of the great rise of tide, which affords scouring power, that even partial success is secured in England, and the case of the narrow channel of the Suez Canal, once alluded to by Mr. Parkes, and the only one at all comparable with Madras as to tide, is so unlike it in many essentials, that reference to this as a case in point is rather difficult to understand.

12. But the real data on which Mr. Parkes bases his calculations are found in his paragraph 17, from which I quote as follows:—

"On one occasion, 1857, an estimate was made by Captain Rawlins, the Engineer in charge of the groynes, of the quantity of sand accumulated in a season by the groynes in front of the fort and by that opposite the light-house, as also those opposite Messrs. Arbuthnot's and the Custom-House. The area was in the aggregate 22½ acres, and the depth 3 to 4 feet, and the spaces were not filled. Taking this, therefore, as a measure of the quantity of sand which could be arrested in one year, I found that in order to fill in a triangular area of similar form between the coast and a pier extending 1,200 yards from shore, a period of 180 years would be required."

That Mr. Parkes committed a fatal error in assuming such as a correct measure of the sand brought up in one season, is abundantly proved by the light of subsequent events.

13. The longest groyne of all those mentioned by Mr. Parkes projected 400 feet from DeHaviland's bulwark. On September 10th of the current year the south pier had advanced 547 feet from the end of the curved loose rubble approach, or nearly 1,000 feet in advance of the longest groyne quoted by Mr. Parkes. At that date all work was stopped (notwithstanding very calm weather), owing to an accumulation of 10 feet of sand at the pier head. In addition to this, there was a distinct line of breakers 250 yards long, extending between the south pier head and the iron pier head in the centre of the harbour. We could not have clearer proof of the fact that even yet we have not any true measure of the quantity of sand brought up in one season. We have not even yet headed the sand, although during the current year (during which alone the 547 feet of block setting in the south pier has been carried on) the progress of work on the south pier promises to be nearly double of what it was at a corresponding stage on the north pier.

14. I do not question our ability to head the sand eventually. It is more than probable that we shall, though it is impossible as yet even to assert this with certainty; but the error in the most important element of Mr. Parkes' calculation stands proved is so glaring, that the necessary correction almost seems to extinguish the life of his harbour. It would of itself certainly justify the stoppage of further expenditure; but I have been anxious, in the first place, to see the fullest justice done to Mr. Parkes, and in the second am strongly of opinion that though his own plan may not achieve complete success, the work that he is now doing may prove an important step towards modifications yielding better results. The importance of a harbour at Madras is far too great to justify the abandonment of the scheme at the first check. The work, so far as it has progressed, seems to point to the necessity of having the harbour detached and the system of construction adopted by Mr. Parkes, well tested as to strength at Karachi, is one that admits of comparatively easy modification by the mere transposition of his material, the expense of the manufacture of much of which represents so large a portion of the total cost of the whole work.

15. My experience of the harbour at Malta, the unsanitary state of which is entirely due to the absence of a current through it, shows the necessity for the correction of this evil in Mr. Parkes' design; and the remedy admits of so much easier application to a detached harbour that this, of itself, is an additional reason for such alteration.

16. The entrance to Mr. Parkes' harbour, presenting two arms directly at right angles to the course of a ship on entering, is one much condemned by seamen. The generally adverse opinion to this feature of the harbour is strongly confirmed by Admiral Bythesea, the professional adviser of Government in such matters, whom I have consulted on the subject. As regards the entrance, the opinion of sailors, headed by Admiral Bythesea, appears to be unanimous in favour of a double entrance, or rather of two entrances from opposite directions, the course of the entering ship being parallel to the coast lines. Failing this arrangement, and supposing only one entrance allowable, their opinion leans to one formed by the north arm overlapping the south. This, though easier for navigation, possesses the great disadvantage of encouraging the ingress of sand to the harbour. This question will receive due consideration in my review of the different proposals for modifications.

17. But there is perhaps no part of Mr. Parkes' scheme, of which those who will be exposed to its dangers more unanimously disapprove than his system of mooring. Mr. Parkes, in his plan, shows 13 vessels swinging in circles, and 3 moored to the present iron pier. Admiral Bythesea briefly condemns this arrangement as one "courting disaster in a cyclone."

18. This question of the method of mooring is closely connected with that of entrance to the harbour, and it becomes necessary to consider the two together. Mr. Parkes in his paragraph 57 says of the arrangement for two entrances—

> "The one undisputed disadvantage is that, inasmuch as a sufficient space must be kept clear in the neighbourhood of each entrance for ships to bring up after entering the harbour, the space required for the second entrance would be lost as mooring ground."

In other words, Mr. Parkes considers that the arrangement as shown by him is the one most economical as to harbour accommodation. Here, again, the opinion of seamen is directly opposed to his. It is to the effect that, supposing 13 ships to be moored, as shown by Mr. Parkes, it would be next to impossible for another ship to enter by a single entrance without fouling one or more of those riding at moorings, the very nature of the entrance necessitating extra width, as well as length of berth within the harbour to enable a ship to bring up with safety. It is quite open to question whether the disadvantage of "a sacrifice of one-fifth or one-sixth of harbour capacity" for bringing-up ground, alluded to in Mr. Parkes' paragraph 58, does not lie rather with his own single entrance, as shown, than with the double entrance to which he imputes it.

19. On the subject of moorings we cannot but be guided in a great measure by the opinion of those who have made a sea-faring life their profession, and this being almost unanimous against the arrangement first shown by Mr. Parkes (which, I may also note, places the amount of accommodation such a system affords in far too favourable a light, as ships could not possibly be moored with such short lengths of cable), it remains next to consider Mr. Parkes' alternative.

20. In paragraphs 44 and 45 of the same report quays are alluded to and proposals for the future are discussed. As Mr. Parkes regards this part of the question in the light of a "second step" for future consideration and not entering into his estimate, it is scarcely fair closely to criticise the arrangement he shows; but I must remark that the quays formed "by another similar break-water at a distance of, say, 100 yards from the first and parallel to it * * * *, the space between the two parallel piers being wholly or partially filled up," hardly appears to be an economical arrangement, as the second break-water shown

outside the first (instead of inside it) would have to be constructed under the same, if not greater, natural difficulties than the first. If such is to be the arrangement, it should obviously have received more consideration in the first instance; and assuming the interior accommodation to be just sufficient as it is, it would have been better to have placed the north and south piers further apart, and laid the second lines of blocks *within* the present piers, which would have allowed of the quays being constructed in still water.

21. I do not, however, think that want of accommodation is one of the charges that may fairly be laid against Mr. Parkes' harbour, provided the depth could be maintained, and if the other objections, to which I have alluded, could be got over. There is within the harbour ample space for quays, and no doubt these, having been proved to be necessary, would have been placed in the most advantageous position by Mr. Parkes. Wharfs, however, form such an integral portion of any harbour which would be of real practical value to Madras (either for shipping or refuge purposes), that I cannot follow his example and omit such an important element from estimates showing to what expenditure we stand committed.

22. It is not easy to follow Mr. Parkes' figures in his last report, in which he lays claim to considerable saving over his original estimate. Colonel Thomason has, with Mr. Thorowgood's assistance, gone carefully into the question, and comes to the conclusion that, supposing the work to be carried into completion according to Mr. Parkes' designs, the eventual cost would probably be R61,99,615, or R3,48,225 in excess of Mr. Parkes' original estimate. Considering the many elements of uncertainty in such a work, and the variations in exchange since the first estimate was submitted, I find nothing in this at which exception need be taken; but, as I shall now proceed to show, this represents but a fraction of the expenditure which must be incurred before Madras possesses a harbour of real practical value.

23. I cannot, I believe, do better than introduce here *in extenso* a memorandum prepared by Colonel Thomason in personal consultation with me:—

Memorandum by Lieutenant-Colonel C. S. Thomason, R.E., on various projects for a Harbour at Madras.

"The scheme which has received the sanction of Government is now in such an advanced stage that much of what will be here discussed may almost seem superfluous, more especially Projects 1A and 1B (Fig. 1, Pl. II), which virtually amount to an entire abolition of what has already been achieved at great cost in the face of great obstacles. It is almost needless to say that no such proposal is contemplated, the object, according to my instructions, being rather to interfere as little as possible with the original design. In order, however, to determine the extent to which such non-interference can safely be restricted, it is necessary to view the question from every possible aspect. The expenditure to which Government already stands committed is a serious one, and seeing how rapidly the foreshore has now advanced in accordance with the expressed anticipations of the opponents to the present design, some justification seems called for when the policy of non-interference has been carried to such an extent.

"The fact is, that the author of the present design himself foretold a rapid advance of the foreshore in the first stages of the work. In comparing the present state of the harbour and foreshore with the plans originally submitted, for the purpose of showing the accommodation contemplated, it is evident that the anticipated acreage of the harbour has already been seriously encroached upon; the inference, therefore, that the present state of affairs is not so favourable as the designer hoped, cannot be considered an unfair one. The original calculations as to the probable life of the harbour bear evidence of having been based on insufficient data. As the work progresses this becomes more and more evident, and until the south pier has advanced at least so far as to head the sand advancing from the south and thereby afford some clue as to the extent of this evil, all projects for a successful harbour in such a situation as Madras—one without precedent—must be more or less speculative.

"It is a favourable feature of the present design that important modifications may be effected by a simple transposition of material: should it therefore not prove as great a success in its present form as was once hoped, it by no means follows that the expenditure incurred has been a profitless one. The experience now gained was not at the disposal of the author of the design in the first instance, and this will, I trust, be held to justify any criticisms that I may now make.

"The present aspect of affairs at Madras certainly points to the necessity of some future important modifications as being more than probable; it behoves us therefore to consider, according to our present lights, what form such modifications are likely to assume, what prospects of success they hold out, and what will be a safe estimate of their cost. These considerations alone will account for the embodiment in this memorandum of such projects as 1A and 1B (Fig. 1, Pl. II). Such radical changes of design may not, and we may hope never will be, necessary; but they are the result of much close observation, present many new features of the case, and will not be out of place if here recorded.

"*Report on Projects Nos. 1A, 1B, and 2 for Madras Harbour.*

"In a letter dated September 16th, 1878, Mr. Thorowgood writes as follows:—

"'The sand at the south pier is now 10′ deep; at that depth I can do nothing; it beats the north pier in 1877.'

"2. At the time the above was written, the purport of which is in exact accordance with my own personal observations a few days previously, the south pier block setting had advanced 547 feet beyond the curved loose rubble approach into what used to be 4-fathom water. When I saw it, a distinctly marked line of surf was breaking (in calm weather) along half of the distance between the extreme points of the south pier and the iron

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pier in the middle of the harbour, taking it roughly, a distance of 250 yards. Such being the facts of the case, it is evident that even yet we have no true gauge of the amount of sand brought up by each south-west monsoon. It is something very considerably in excess of what the present south pier is capable of arresting. How much in excess, no one can say, and under such circumstances it is impossible to place any faith in the constantly diminishing estimates of the time that will elapse before the foreshore will reach the mouth of the harbour, which have hitherto been advanced by the designer. The evidence before us certainly points to the conclusion that this result will be attained very much sooner than he anticipated. I hope I may prove wrong in thus prophesying, but having such strong convictions on this head, some justification seems necessary for my having hitherto refrained from giving expression to them. The fact is, I believe, that Mr. Parkes is helping us materially in solving the problem of a Madras Harbour; but that the successful harbour when completed will in plan at all approach to the present design appears to me improbable.

"3. The first thought that must strike any one seeing the action of the ocean on the Madras Coast must be the force that nature is constantly bringing to bear. There is force enough, and to spare, there to effect anything within our requirements, be it the transmission of the sand, or anything else; and the first objection that would strike an observer to the present scheme would probably be, that instead of attempting to utilize this force to pass on the sand, there has been abruptly opposed to it, where it would be most useful, an obstacle in the form of a very efficacious break-water, the strength of which has already been well tested at Karachi.

"4. If the harbour is in any sense to be a permanent one, the conviction that it must be detached from the shore, as has all along been contended for by Sir A. Clarke, is one that could scarcely fail to obtrude itself on the mind of any observer of the present state of affairs. How far it should be removed, and what should be its extent and form, are not questions that need be answered altogether empirically.

"5. As far as we can judge, the sand under ordinary circumstances is not much in motion beyond the 4-fathom line. It is true that a heavy sea, whether due to strong local breezes or a ground swell, will often discolour the water far beyond the 4-fathom line, and the water is often seen discoloured far from shore without any apparent reason; still the evidence of divers goes far to prove that the disturbing influence of the waves on the sea bottom does not to an appreciable degree extend beyond this 4-fathom line. This, therefore, may be accepted as a safe limit for the space intervening between the shore and harbour; it may, perhaps, even be slightly encroached upon with impunity provided the form of the inner face of the harbour be modified as noticed hereafter; but it is essential that the waves be allowed the freest action possible between the harbour and shore. A certain amount of their force must be lost—absorbed by the harbour walls—in order to procure still water within the harbour; but there should still be an ample reserve to carry the sand well past the centre line perpendicular to the shore, and the form of the harbour should be so designed as to encroach on this reserve as little as possible.

"6. It becomes the more necessary to conserve this force of the waves, because at Madras, as far as we can judge, it is the only force of any practical importance at our disposal. The tide ebbs and flows within limits only little over 3½ feet measured vertically, which places out of the question such a remedy as that adopted by Smeaton against the shoaling up of the Ramsgate Harbour, namely, the reservation of a certain portion of the tidal basin as a flushing reservoir—a measure after all attended with but partial success.

"How necessary it is to secure some scouring force is well illustrated in the harbour of Boulogne, which not only enjoys a considerable rise of tide, but has also a valuable adjunct in the River Lianne, which, though having too small a discharge for permanent scour, is of great value in filling the scouring reservoir. Still, notwithstanding these advantages, we know the difficulty there is in keeping clear the mouth of the Boulogne Harbour.

"7. Added to all these disadvantages, Madras seems to be peculiarly wanting in local currents. Three miles an hour is the maximum with which it can safely be credited, and even that appears to be entirely dependent of wind, and considerably weakened as the shore is approached, where it would be useful. Speaking from personal experience in both monsoons, I cannot say that I have ever noticed a current of anything like 3 miles an hour, nor have I ever noticed the ships riding any way but head on to the gentlest of breezes, from whichever direction they may be blowing.

"8. The waves then being the only reliable agents at our disposal, it is impossible to study their action too closely. It will be noticed in one of the designer's earliest reports how fully alive he was to the fact of the sand being almost entirely wave-borne, and, knowing this, it seems difficult to account for his having made enemies, instead of friends, of the waves.

"9. How these waves transport the sand is most clearly recorded by varied markings on the sand at different points along the shore. Photographs of these markings, and my notes thereon, will be found in Appendix,* and I will here confine myself to the general deductions therefrom.

* Appendix IV. and sheet of photographs.

"10. Observations on the waves during both monsoons appear to prove that in the south-west monsoon, the 'strike' (speaking geologically) of unobstructed waves, *i.e.*, the line of their crests, approaches the shore in one way at a maximum angle of about 30° with the foreshore, and in the north-east monsoon 30° the reverse way, *vide* Fig. 1, Pl. I. It is when this angle is at a maximum that the sand travels fastest down the coast in the north-east monsoon, and up it in the south-west monsoon. As the monsoons change, the waves veer round, and for some time come dead on to the shore, when the sand ceases to travel. Obstacles in the form of groynes also locally produce the effect of changing the bearing of a wave's crest. For instance, *vide* Fig. 2, Pl. I, when the waves are approaching at the angle of 30°, supposing a portion of the shore, as from *a* to *b*, to have its bearing to be so changed by a groyne as to run roughly parallel to the crest of the approaching waves, markings in the sand at this point will be wanting, and the sand will not travel there until conditions are changed by the constant action of the waves telling first upon the most advanced or the most retired portion of this abnormal stretch of foreshore according to circumstances. From this it would appear that had the harbour piers, *vide* Fig. 3, Pl. I, instead of being run out perpendicular as *b c* and *e f* to the foreshore, been run, the south pier parallel to the crests of south-west monsoon waves, and the north pier parallel to the crest at the north-east monsoon waves, when approaching the shore of their maximum angles (as shown by dotted lines *h f* and *g c*), the sand could not have travelled along these faces until the angles *c g i* and *f h j* between the piers and the foreshore were filled up; and, secondly, that these angles could not have filled up if the pier (or rather, in that case, harbour

walls), instead of starting from the shore, had been so detached as to allow free scope for the action of the waves without wasting their force, as shown in Fig. 4, Pl. I. How this might be effected will be considered presently; but so far we seem to get a clue to the proper lie of the face of the harbour. This reasoning, if right so far, would tend to show that the two closing arms of Mr. Parkes' harbour, instead of running parallel to the foreshore as *a b* and *c d*. Fig. 5, Pl. I, should be inclined at 30° to it, the south arm parallel to the south-west, and the north arm parallel to the north-east monsoon waves when at their maximum inclination, according to the dotted lines *a e* and *f c*. Reasons for modifying this in practice will be given further on.

"11. For facility of construction, an angle appears preferable to a curve where the piers begin to converge to form the front of the harbour.

"12. Placing aside, for the present, the question of detachment, the harbour now under construction would thus far only be modified to the extent of being angular instead of curved where the piers take turns to form the face of the harbour, and the two arms forming the face, instead of being parallel to the foreshore, would in different directions be inclined to it at an angle of 30°, the space between their extremities forming the entrance being 450′ wide, as before. Fig. 6, Pl. I, shows the harbour as modified thus far.

"13. The entrance, as fixed at present, is almost universally condemned by nautical men; and there is reason to suppose that the designer himself intends to re-consider it. That at which we have so far arrived in Fig. 6, Pl. I, is but a shade better. A single entrance always must be a difficulty, as it always has been with all its modifications at Ramsgate. There is a good reason why it should be a still greater one at Madras, for there it is quite impossible to say from what point within 180° the strongest wind will blow at critical moments. The gales differ entirely in their character from those prevailing on the English coast. To use the words of Captain Taylor, the Master-Attendant at Madras—'The only gales at Madras are cyclones.' Such being the case, two entrances appear to follow, the safest course for ships entering being one parallel to the shore. To close the single entrance, and provide two entrances where it is intended that the piers now under construction will curve inwards, would secure this.

"14. Supposing still that the north and south piers stand as designed, if a single entrance be also adhered to, in order to satisfy nautical men it should be formed by the northern arm overlapping the southern one, as in Fig. 7, Pl. I. But the sand travels up from the south, and the harbour in such case must become a silt trap, worse than with the entrance as already designed, where there is every chance of a great deal of the sand being carried past the harbour mouth without entering it. The most promising modification of this form of the north pier overlapping the south is, perhaps, that of the north pier being carried straight out to sea, the east face of the harbour inclined at 30° with foreshore line, and the north pier terminated at the prolongation of this harbour face. The entrance between the north pier and the east face of harbour would be 450′ wide, as before. This will be considered as a separate project, involving the minimum of interference with existing design, and is illustrated in Fig. 3, Pl. II.

"15. On the other hand, if the entrance be formed by the south arm overlapping the north one (*vide* Fig. 8, Pl. I), ships must enter from the north-east, the direction which of all others seamen look upon as the most awkward.

"16. Many have argued against the double entrance arrangement as tending to increase deposits within the harbour, but their arguments seem all to be based on the supposition that sand must be travelling at the entrances, or that the square connected form of harbour is retained, which in process of time must advance the foreshore to such an extent as to lead to that result eventually.

"17. In one of his early reports, Mr. Parkes, while maintaining that sand to an appreciable extent is not travelling in water of such depth as is found at the curves, admits that the diminution of depth (with his design) is simply a question of time, and there can be no doubt that the life of a square connected harbour would be much shorter with the double than with the single entrance. If the reasoning for the modifications here advocated according to Figs. 1 and 2, Pl. II, is correct, the sand will here travel with little or no obstruction past the east and west centre line of the harbour and *between* the harbour and the shore, and the foreshore therefore cannot advance. It will, therefore, never affect either of the two entrances proposed, and this argument against the double entrance thus falls to the ground. It will be seen, moreover, that the centre line of the entrance channels bisects the modified harbour under discussion, and whatever currents may pass through it naturally, or may be coaxed through it artificially at various points (which could be easily effected), being of clear water, would tend to keep sweet the water within the harbour, and thus remove one of the great objections to the sanctioned design, the impounding so great an extent of stagnant water covered with ships at anchor.

"18. Fig. 9, Pl. I, illustrates the modifications, including the two entrances thus far advocated, and it will be observed that the eastern portion here proposed for the harbour is in fact an entirely detached break-water. Having no connection with the shore, no object will be attained by providing it with wharfs. Communication with shore when necessary will be maintained by means of boats, which, owing to the efficiency of the approved break-water section, as tested at Karachi, would always traverse still water.

"19. The waves at Karachi have been measured 14 feet from trough to crest, and the highest observed by Mr. Chisholm at Madras in the 1877 cyclone was 10 feet. The assumption, therefore, that the Karachi section will suffice for the Madras break-water, appears admissible; but behind this break-water, jetties of a section somewhat modified, to which ships could be safely moored fore and aft, appear safer than the present proposal of having them swinging at moorings. Of the proposed harbour with two entrances the portion east of entrance channels would be a harbour of refuge, and one of fair capacity. The flanks of the break-water (shore end) would be prolonged parallel to the shore to further protect the entrance as illustrated in Fig. 10, Pl. I, the extent of such prolongation being depended on the form of the remaining half of the harbour, which it is proposed next to consider. Before leaving this part of the subject, however, I would note that the form here laid down for the break-water is one that is open to considerable modification in details, *vide* arrangement shown dotted in Fig. 18, Pl. I, and proposed for adoption in the projects illustrated dotted in Figs. 1 and 2, Pl. II, to which allusion will be made hereafter, as we are at present dealing rather with main principles than details.

"20. In planning the portion of the harbour within the entrance channel, the main object had in view is the conservation of the wave power, on which alone we can depend for keeping the harbour free from the influence of the travelling sand. This is by far the most important part of the whole design, and it becomes necessary to explain as fully as possible the principles on which it is based.

"21. During the north-east monsoon, when standing on the north pier at point *a* (Fig. 11, Pl. I), I was particularly struck by the behaviour of the waves then rolling past the point of the pier which they were approaching with about their maximum sand-transporting power (which I have assumed to be when the angle between the line of the wave crest and the shore is 30°), on reaching the pier, which divided it into two sections. The left or seaward section most markedly advancing, 'left shoulder forward.' It regularly wrapt round the pier head, and striking the shore something like a south-west monsoon wave, created an eddy in the angle formed south of the north pier by the pier and foreshore. Of this there cannot be any doubt, for the record of this eddy is seen in the accompanying photograph of the sand markings at this point. Of the behaviour of the right section of the wave I am not quite so sure. I am under the impression that it continued its progress rather with a tendency to *right* shoulders forward, and the photograph of the sand markings rather confirms the idea, the angle between the 'strike' (speaking geologically) of the wave 161°, and the *general* bearing of the coast line 196°, being (196°—161°=) 35° instead of 30°. Had the pier been longer, it is probable that this section of the wave would have wrapt round the pier, or 'changed front' a good deal more; in other words, that the angle of approach would have been a good deal more even than 35°.

"22. Let us imagine, as in Fig. 12, Pl. I, a full south-west monsoon wave striking the southern portion of the break-water, as here laid down. Supposing there to be no flank to the break-water, the wave would come dead on to the southern portion, but the southern half of the break-water would divide the wave into two sections, the seaward one of which would advance right shoulders, forward beyond the break-water (as the seaward section of the north-east monsoon wave in last paragraph advanced left shoulders forward), and when passed the break-water, the angle between the 'strike' of the wave and the coast bearing would be a good deal less than 30°. The behaviour of the landward section would be analogous to the right section of the north-east monsoon wave of the last paragraph. It is probable that it would 'change front' fully to the extent of 50°, the maximum of our requirements.

"23. As the most unfavourable view, let us imagine, as in Fig. 13, Pl. I, that this landward section would not change front at all, but advance to the shore exactly as if there were no break-water. From the extreme end of the break-water flank if a line *a b* be drawn perpendicular to the strike of the wave, it would meet the east and west centre line and foreshore a little in advance of the starting point *b* of the pier, and if a wall were constructed along this line, the wave, in rolling along it, would be subject to no greater reduction than that caused by the friction of the wall. Whatever sand was in motion would be carried with the full force of the wave to the starting point *b* of the pier and deposited there; for the best of reasons, that there is no room for it to pass.

"24. Let us next suppose, *vide* Fig. 14, Pl. I, the angle with the strike of the wave subtended by the shore to be increased from 90° to 120°. The line which before cut the east and west centre line of the harbour near the start of the pier would now cut this line at *b* about 700' in advance of the pier head in 5½-fathom water. If a wall be constructed along this line, with the necessary opening into the harbour, this would be one of the inner faces of the portion of the harbour first proposed here for construction. The wave, in passing the break-water flank, would be subject first to reduction due to the opening into the harbour (represented, let us suppose, by *a c*) which is unavoidable; but once past that, it would be confined by the inner wall of harbour, subject only to a reducing angle of 30°. What power the wave would thus lose in one way would probably be more than made good in another, for it would be entering a constantly narrowing channel which we know on a large scale (in the Hooghly river, for instance) so concentrates its power as to create a bore. If this reasoning is correct, the force of the wave would be so far increased as to render absolutely necessary the sea wall *d e* which it is intended under any circumstances to construct along this portion of the foreshore containing the main sewer for carrying off the town drainage. It is anticipated that the sand will be carried with such force past this centre line, with the help of whatever current there may be, as at least in a great measure to be transported beyond the bed of the harbour.

"25. Project 2 (Fig. 2, Pl. II) shows how a short extension of the break-water would admit of another inner wall (like the first to be a wharf wall) running parallel to the first, thereby admitting of a very great increase of harbour accommodation, without bringing the harbour itself nearer to the foreshore than the head of the present pier, about the limit at which the sand is generally in motion to any appreciable extent. There would, probably, even with such an extension of harbour accom modation, still be ample room for the whole of the sand in motion to pass between the shore and harbour.

"26. The northern half of the harbour would, of course, be symmetrical with the southern, and thus enable the north-east monsoon to pass back the quantity of sand due to it.

"27. An obvious modification of the entrance *a c* of Fig. 14, Pl. I, to suit the break-water portion illustrated in Fig. 10, Pl. I, is shown in Fig. 15, Pl. 1, where the extent of the prolongation alluded to in paragraph 19 is determined by the prolongation of the alignment of the inner harbour walls. The seaward portion of the harbour would be disconnected and devoted primarily to the protection of shipping in foul weather, the inner portion being connected (by means of an open pier) with the foreshore and used for wharfage, both portions being provided with jetties, &c., for extra accommodation. It will be observed that the harbour thus designed is a disconnected one with two entrances, (roughly) diamond-shaped, with a major axis lying parallel to the shore about double the minor one perpendicular to it, as opposed to the present design, abutting on the shore with one opening, and roughly square in plan. The harbour now in progress presents a full side as an abrupt obstacle to stop the advancing sand, whereas the proposed modification presents the acutest angle of an elongated figure to pass it.

"28. I would here call attention to two cases (on a small scale) illustrative of this new principle. One is the wreck of the *Invereshie* stranded beam on close to the fort. It will be noticed that there is always water between the wreck and the shore. Again, during the late famine crisis, the *Duke of Sutherland*, one of the long steamers of the Ducal line, got ashore in the same way. Eye-witnesses affirm that the sand rapidly advanced close to her, but *never reached her*. There was always a deep, though narrow, channel of water between the ship and the shore, and she was eventually got off. Both these are, in a small way, instances of the principle of presenting the acute angle of an elongated figure to the run of the sand. The run of the ships' lines is specially adapted to pass waves with the smallest amount of friction, and the result would probably have been different had the ships been of uniform rectangular section throughout. A groyne may be taken to be an illus-

tration of that involved in the present harbour, and for the sand to head that is, as far as we know, simply a question of time.

"29. But if, under conditions obtaining at Madras, harbour walls connected with, and running perpendicular to, the foreshore are objectionable, it appears to me quite an open question whether the mere detachment of such walls from the shore, as in Fig. 16, Pl. I, will be an effectual remedy. On the other hand, the presentation of too acute an angle, as illustrated in principle in a simple break-water running parallel to the shore (one of the first proposals for Madras, and shown in Fig. 17, Pl. I), need not necessarily have remained detached. The angle of reduction of the wave's force, instead of being 30°, as in modifications now under consideration, would have been 60°, there would have been no narrowing channel to receive the in-coming wave, and it may be open to question whether the force of the waves would have been sufficient to tell with effect to point *a* within a distance of 200 yards of the east and west centre line or even so far; or (supposing the break-water to run roughly north and south) past an east and west line *of* 800 yards north of *d*, the southern extremity of the break-water. In a similar way the north-east monsoon waves might have been ineffective beyond point *b* on an east and line *b e* 800 yards south of the northern extremity. Mr. Robertson's (or perhaps rather Colonel Orr's) break-water was to have been 2,000 yards long in 7-fathom water, so that between these two east and west lines there might have been a stretch *a b* of 400 yards of still water, and if so, the whole of the 400 yards would have silted up, and before long the shoal would have extended out to the break-water. The break-water would have been in fact, according to this supposition, too long for its distance from shore; and if there is not under such circumstances some such fender as project 1A (Fig. 1, Pl. II) provides in its inner wharf walls *a b a c* of Fig. 15, Pl. I, to prevent this accumulation of the sand in the form of a spit from the shore reaching the break-water, reach it must sooner or later.

"30. Mr. Robertson at paragraph 61 of his report says—'If there is such an immense quantity of sand in motion on the shore of Madras as to be beyond the power of control by groynes or otherwise' (Mr. Parkes himself acknowledges that the sand must eventually prevail), 'then my opinion is, that even a break-water will not succeed. It would still the surf, and thus remove one of the two agents which move the sand, and *I do not think it will have any effect in strengthening the currents*.' The italics are my own, and this is the only point where Mr. Robertson and I are at issue, for I think that it is possible by the means here specified (the inner harbour wall thus placed), if not to strengthen, at any rate to maintain, sufficient force of current for all practical purposes. I agree with him that a simple break-water would not have this effect.

"31. It is quite possible that even with the modifications here suggested there will be heavy deposits to leeward of the harbour, to the north-west of it in the south-west monsoon, and to the south-west of it in the north-east monsoon. There must be such, for after the body of water has passed the east and west centre line, it will impinge on the sea wall, be reflected back, and will meet with counter-currents causing eddies, and therefore to some extent shoals: but it must be borne in mind that owing to the 'wrapping round' action of the waves in passing the obstruction of the harbour, alluded to in paragraph 21, the area to leeward of harbour free from wave action would be comparatively small, so that much of the sand would be carried past the 'hitch,' and continue its course northwards. What remained need not prove objectionable, as the ensuing monsoon would clear it away, provided a deep channel were left on the shore side of the inner harbour wall, as in the cases of the stranded *Invereshie* and *Duke of Sutherland*, alluded to in paragraph 28.

"32. It can scarcely be considered as a principle involved, but it certainly is a result, and a very important result, of the form of construction here suggested, that none of the wharf walls can be exposed to the direct action of violent waves. East of the entrance channel, as noted in paragraph 27, is devoted ntirely to harbour of refuge. None of the vessels moored there will be moored broadside on to the break-wate., but to piers projecting inwards from the break-waters shown in Figs. 1 and 2, Pl. II, and will thus lie end on to the approaching waves the force of which before reaching the ships will be entirely destroyed as we see at Karachi. West of the entrance channel will be devoted to wharfs and piers, each affording the accommodation of four lines of rail (with crossings, &c.), converging on the bridge, in the centre, connecting the harbour with the shore. It is not thought worth while at this stage to prepare detailed plans and estimates for this bridge, but liberal allowance has been made for it at a rate per foot run on data kindly furnished by Mr. W. C. Furnivall. The piers supporting it should, of course, be as open as possible in order to prevent the smallest obstruction to the waves passing under it.

"33. This arrangement affords many advantages over the single entrance harbour now under construction, *viz.*—

"*1st.*—A long straight run to an entering ship to bring up in.

"*2nd.*—Choice of entrance according to the prevailing wind and weather.

"*3rd.*—The smallest possible waste of space within the harbour, and consequently maximum of accommodation.

"*4th.*—Great safety to the ships in the harbour.

"*5th.*—Every possible facility in the transhipment of goods.

"*6th.*—Great saving in first construction, as the wharf walls, &c., not being exposed to violent waves, may be made at least 10 feet lower, and also need not be of so substantial a nature as would otherwise be necessary.

"*7th.*—A large comparatively protected area (the exact extent of which it is impossible as yet to define) between the harbour and the shore.

"*8th.*—The facility with which, at the expense of a very small extension of break-water, works trebling the wharfage accommodation may hereafter be easily executed in still water.

"*9th.*—Cleanliness of the harbour itself owing to the gentle current always flowing through it.

"*10th.*—Independence, after first construction, of such expensive adjuncts as dredgers, &c.

"*11th.*—Independence of the town and its sewerage.

"*12th.*—Facilities for efficient supervision of Police and Customs Officers.

"34. At the conclusion of paragraph 10, after detailing the principles on which I have designed the face of the harbour, I have said that I think that the face so designed may be advantageously modified, and I propose now to show how this may be done.

"35. Referring to Fig. 15, Pl. I, it will be seen that each of the harbour faces is composed of two sections, one *d e* inclined at 30° to the foreshore, and the other *e f* parallel to it. At the junction of these two we have

an angle re-entering to the shore. This is always objectionable in any sea wall opposed directly to the action of the waves, as the waves at the angle exert almost an explosive force, well illustrated in one of the re-entering angles of one of the forts at Boulogne. This evil would no doubt in a great measure be remedied by having at the angle a (say circular) portion *g*, Fig. 18. Pl. I, detached slightly from the two sections *h i* and *j k* of the face. It is possible in such a case that the small portion of the wave fixing vent through the openings on either side of this circular portion would not create any commotion within the harbour worth noticing. But there is one objection to this form, namely, that, if the harbour is ever extended to the possible dimensions shown in project 2, though a slight extension of the break-water parallel to the shore would give calm water behind it, in which to carry on the works of extension, still there would remain a deficiency of refuge harbour accommodation which may now be secured at comparatively trifling additional cost by following the dotted alignment shown in plan—also shown dotted in Figs. 1 and 2, Pl. II— which would at the same time not in any way injure the wave force outside of the harbour which it is proposed to utilise for transporting the sand past the centre east and west line. If the dotted form be adopted, the advancing wave would wrap round the curved face with a rolling action very different to the shock resulting from coming dead on to a long straight wall, or, still worse, where there is a re-entering angle to receive it. The curved form here appears to be the strongest, and with such a long radius would not present any difficulties in construction. It would, moreover, very notably increase the refuge harbour accommodation, and by so much perhaps postpone the necessity for more expensive works of extension.

"36. In order to make the matter as clear as possible, an abstract is attached to each plan in Pl. II showing the cost and accommodation of each project. A comparison between the results as regards the angular and curved break-water seems to decide the question in favour of the curved form, which it would be preferable to adopt, even if the cost of such a course necessitated the postponement of jetties to a more convenient time.

"37. In the construction of this harbour the whole of the concrete blocks laid down for Mr. Parkes' scheme would be taken up and removed into new positions as indicated in plans and sections (*vide* Pl. II). The rubble base now deposited, if covered with 22½' water, would be left undisturbed, as it would not appreciably affect the force of the wave, and it might not pay to take it up; but everywhere else it should be dredged out, and utilised elsewhere. Mr. Price, the Superintendent, Karachi Harbour, has done this at a cost of R1-11 per ton.

"38. For the removal of the blocks I have taken a rate of R30 for each block 12' × 8' × 4½' at which both Mr. Thorowgood and myself think it might be done. For removing those already placed, special arrangements would be necessary, but in laying down those hereafter special orders might be issued to insure the lower hole not getting filled up with shells, &c., which they otherwise will do very quickly. This is a very trifling matter, attention to which now may save many thousands of rupees hereafter.

"39. There would not be the slightest necessity for bringing the break-water first into connection with the shore for the purpose of constructing it, and subsequently isolating it. Even already the steam hopper barge can come alongside the northern pier to take in her cargo of stone, and the southern pier will very soon be sufficiently advanced to offer similar facilities. Under these circumstances, with proper arrangements for forming an artificial island in the centre of the proposed break-water, from which the work might simultaneously progress outwards in both directions, the expense would not be of the prohibitive nature that stood in the way of the entertainment of a break-water project in the first instance, and there is no reason why this part of the work should not be completed as soon as any other, say within six years.

Report on Project No. 3 (Fig. 3, Pl. II)—(Least modification of Mr. Parkes').

"This project is drawn up on the assumption that the foreshore will, with such an obstruction, advance to a certain extent every year; that it is only a question of time when the sand will creep round the harbour mouth. The object here is to postpone this time as much as possible; hence the inclination of the harbour face 30° to the line of foreshore.

"The north pier will be carried straight out so as slightly to overlap the harbour face, leaving a passage of 450 feet for ships to enter by. This is perhaps the best compromise to meet the conflicting requirements of the nautical man and the engineer, where there is only one entrance. The north pier, as also the narrow portion of south pier and harbour face, will, except in very fine weather, serve as break-waters only. Judging from present appearances it will not be very long before the sand will reach so far along the south pier as to render what is shown drawn thick as available for wharfage. According to this plan the wharfs will be constructed in still water and by so much cost less; the ships will be thoroughly protected; entering ships will have the whole run of the harbour to bring up in clear of ships already moored; there is the minimum of interference with sanctioned design, and the cost is perhaps the least at which the capabilities of the harbour can be developed.

" *Report on Projects Nos. 4, 5,* and 6.†* (*Pl. II.*)

"I have in No. 4 endeavoured to work out a design as strictly as possible in conformity with one discussed before Sir A. Clarke. The main features are :—*1st*, the north arm overlapping the south, suggested by Admiral Bythesea as better from a nautical point of view than with the south overlapping the north; *2nd*, wharfs and jetties 60 feet wide provided with four lines of rail and traffic worked by means of turn-table; *3rd*, a 600' passage cleared out, between foreshore and harbour; *4th*, the harbour to be separated from this passage by an arched causeway, provided with flooring, the minimum depth of water on sea-side of this causeway to be 20 feet and the maximum on land side to be 12 feet, and the dimensions of arches such as to pass cargo boats; *5th*, the dividing channel to be spanned by three bridges with piers as open as possible; *6th*, the dividing channel to be kept open by means of a rake boat or other applince, keeping the sand in suspense until carried through the channel by the current.

"No. 5 is a modification of the above, the chief feature of which is the substitution of curves for turn-tables Besides the great increased convenience in working the traffic, this would, I think, enable us to dispense with two

* Project No. 4 slightly modified.

† Another modification of Mr. Parkes', but with two entrances.

of the bridges spanning the 600 feet dividing channel, an advantage not only in point of economy, but also as offering less resistance to the current. I believe one bridge with four lines of rail would amply suffice for the traffic, whilst No. 5 shows a saving (roughly) of 10 lakhs over No. 4, the interior harbour accommodation of the two being practically the same.

"The cost of these two designs is much aggravated by,—*1st*, the necessity for extra height to pass the cargo and rake boats; and *2nd*, the extra strength of section in parts exposed to full action of the waves.

"I have already so fully detailed my own views regarding the motion of the sand along this coast, and the reasoning on which these views are based, that I must beg indulgence if I here reiterate an opinion unfavourable to this form of dividing channel. If that reasoning is right, this channel must speedily close, and with an observation before me, which Lieutenant Love and I recorded of one wave alone depositing sand to the depth of $\frac{1}{16}$ths inch, I cannot think that any system of dredging or raking will be practically capable of coping with such accumulations. If I could conceive the existence of any real current in such a channel, I might judge differently; but all my observations tend to disprove the existence of any such currents of any importance at Madras, except those due to wind and waves, both of which are carefully excluded from this channel; and even were it practicable so to keep this channel open by artificial means, the expense (which I have no means of estimating) would be a serious, if not an insuperable, objection from a financial point of view.

"No. 6.—If there is to be such free inter-communication between the harbour and dividing channel, I do not see that project No. 6 would be liable to have its dividing channel more readily closed than Nos. 4 and 5. There is a material saving in the cost of No. 6, which dispenses with the arched causeway, and there is accommodation for 24 instead of 26 ships, the three centre jetties alone being available; but there is one serious objection, which is that the distance between the two outer jetties (which would be merely break-waters) and the nearest wharfs would only be 560′ instead of 800′, which I have everywhere assumed as the necessary length in which to turn a ship 400′ long, which I have taken throughout as the typical length in calculations for accommodation.

"The arrangement of wharfs in No. 6 is one for two entrances, which I have adopted accordingly—

"*General Abstract showing cost and accommodation of the Harbour project.*

Number of Harbour projects.	Cost.	Accommodation for Ships.						Remarks.
		Refuge harbour.	Wharfage.			Total.		
			In cyclones.	In heavy weather from one quarter.	In fair weather.	Minimum.	Maximum.	
Harbour in process of construction	Rs. 61,99,015	...	(?)	...	...	16	22	No wharfage in this design.
No. 1A	1,37,77,698	8	8	12	16	16	24	Fig. 1.—Without piers and wharfs.
„ 1B	1 48,29,886	8	16	20	24	24	32	Fig. 1.—Differs from No. 1A in addition of jetties with wharfs.
„ 1A modified break-water .	1,50,52,407	20	8	12	16	28	36	Fig. 1.—Modified break-water shown by dotted lines without piers and wharfs.
„ 1B „ „ .	1,61,04,596	20	16	20	24	36	44	Ditto with piers and wharfs.
„ 2	2,28,88,312	28	52	60	68	80	96	Fig. 2.—Addition of second line of wharfs and jetties, and break-water to protect the same.
„ 3	1,02,32,279	...	26	46	64	26	64	Fig. 3.—Least modification of harbour sanctioned and being constructed.
„ 4	1,52,52,131	...	26	32	49	26	49	Fig. 4.—Modification discussed before Sir A. Clarke.
„ 5	1,42,67,862	...	21	32	38	21	38	Fig. 5.—Same as No. 4, but slightly altered by Lieutenant-Colonel Thomason.
„ 6	1,18,07,376	...	24	30	36	24	36	Fig. 6.—Distinct proposal by Lieutenant Colonel Thomason for two entrances.

24. Colonel Thomason regards the necessity for gorging the waves as a possible remote contingency, and as such, he has done right in fully discussing the question. The whole scheme for a harbour at Madras opens up engineering questions, for the solution of which it is very often difficult, if not impossible, to quote precedent, and nothing that can tend to aid in arriving at success can be deemed irrelevant. We are both in accord as to the necessity for detaching the harbour from the shore, though not quite so as to the means that will suffice to render the detachment permanent. My own impression at first was that an open channel of 600 feet width between the harbour and the shore would prove sufficient, but after the experience of the last south-west monsoon, I very much question whether any eastern boundary for the isolating channel short of the 3½-fathom contour will suffice, and this agrees very closely with that fixed upon by Colonel Thomason. Until it has been tested experimentally, it is impossible to say how far the mere action of waves and current will keep open this channel of uniform section. My own impression is that if it will not keep itself open, the tendency to deposit may be controlled by mechanical means, whether dredger or rake. The new principle which Colonel Thomason has introduced in his design of keeping the dividing channel clear by means of the force of gorged waves is one the soundness of which I am not prepared to dispute. My only objection to it is one for which he is not responsible, namely, that the change is of too radical a nature. As a further means of averting failure in the solution of an entirely new engineering

problem, the suggestion is a useful one; but we both agree as to the advisability of first trying the effect of a simple dividing channel extending to the 3½-fathom line, the failure of which would in no way preclude or increase the cost of subsequently introducing the principle of gorging the waves should this be found necessary.

25. The capacity of the harbour as originally designed cannot be considered to be in excess of the requirements of Madras, but the acreage has already been so far encroached upon that, in the opinion of some seamen, it is already a question whether some of the long steamers of the Ducal line could without running ashore enter the harbour of reduced acreage except at dead-slow speed, which would be out of the question with any sea on, so that the extension of the piers into deeper water than was at first contemplated may be safely accepted as an alternative to expensive dredging within the original limits. It is necessary at once to arrive at some decision on this point, as the Superintendent of the Harbour Works has expressed a hope that about next July the north pier will have reached its eastern limit short of the curve to the south. It is premature yet to so fix the limits, and on no account should the curve be commenced until sanction has been accorded. No sand, as far as has yet been observed, enters the harbour round the north pier, so that even if a further extension seaward be not eventually determined upon, a temporary stoppage of operations on the north pier can do no harm. We cannot be too careful about not committing ourselves until some just approximation of the quantity of travelling sand has been arrived at by the fact of the south pier having well headed it, which it has not yet done. As far as we can yet judge, my opinion tends in favour of an extension of both piers to a further distance eastward equivalent to the distance of the 3½-fathom contour from the original foreshore. After much careful consideration, I feel compelled to condemn the single entrance in favour of two entrances, and in this I find myself supported by every seaman whom I have consulted on the subject.

26. Assuming that the future harbour be a detached one as above, the question arises as to what should constitute the division between the harbour and the isolating channel. I confess to a great feeling of uneasiness as to the sanitary result of impounding so great an area of still water, which will, in all probability, be extensively crowded with shipping. It is possible that the open character of the enclosing piers may aid materially in establishing an efficient current, but to my mind this is very doubtful. In one of the projects accompanying, allowance has been made for an arched masonry dividing wharf, but the cost of such an expedient proves so great that it will be better to first try the effect of depositing here, in the form of a sand-bank raised above high water mark, the sand dredged from the bed of the isolating channel. Should it hereafter prove necessary to have recourse to some partition of a more open character admitting more freely of the passage of water, the sand-bank so formed will prove useful as a starting ground for wells necessary for foundations, and may subsequently be easily removed as found necessary.

27. The foreshore between the piers which now intercepts and absorbs so large a quantity of town sewage cannot safely be left in its present state. The sea wall carrying the intercepting sewer cannot be put in hand too soon, and must be regarded as a fair charge on the harbour within these limits, provided the Municipality or Local Government will undertake to extend the sewer to some point where it cannot affect the harbour. Probably the distribution of the sewage on to the land, as advocated in Major Tulloch's report on the drainage of Madras, will prove not only the safest, but also the most economical, course to adopt.

28. The extent to which this saturation of the foreshore has extended was clearly brought to light in borings which Colonel Thomason executed near high-water mark to the depth of 7 fathoms for the purpose of determining the depth at which clay might be found. Observations of the clay stratum at different points on the shore led to the supposition that it might perhaps be found at a depth of about 3 fathoms, but throughout the 7 fathoms bored nothing but sand was found, many strata of which were black, evidently owing to saturation with sewage as seen on the surface of much of the sand between the town and the sea. A breakdown of the boring apparatus prevented the boring being carried to a greater depth, but observations of the sea bottom as far out as the 9-fathom contour still showed sand.

29. The existence of this sand underlying the whole harbour might perhaps be looked upon with some suspicion, more especially as an old break-water constructed by Colonel Cotton in 3½-fathom water had virtually disappeared. Its remains have, within the past year, been discovered near the pier-head by the diver, the boulders composing it being strewed over the bottom. It is, however, easy to account otherwise for this failure, as the break-water was only built up to within 5 feet of low-water level in a position much exposed to the breaking surf in weather, but ordinarily stormy. Mr. Thorowgood, I understand, has been carefully looking out for subsidence since work was commenced, but beyond that which might naturally be expected as due to the first settlement of the material deposited, nothing more has been detected, and in this respect, therefore, I think the site selected may be considered safe.

30. My convictions then being that the design at present being carried out cannot prove successful, I would propose that—

1st.—The north and south piers at present under construction be advanced as far as the entrances to the harbour shown in Pl. III, the remainder of this design being carried out by

2nd.—At once putting in hand the sea wall and sewer.

3rd.—At once commencing the open pier with a double line of wells and with 100 feet spans from C (the end of the present iron pier) to D, at the same time doing as much to similar new pier (on wells) from C to E as it is possible to do without interfering with the traffic on the present pier.

4th.—At once commencing the formation of an artificial island at F; the island to be of *pierre perdue* 800 feet long from south to north and 400 feet from east to west, these measurements being at high-water mark. The island being completed, the rubble base should be laid from it to G and H, and to I and J.

5th.—When the present north and south piers shall have reached their assigned limits, the Titans should be moved on to the artificial island and proceed with laying the blocks necessary to complete the break-water portion of the harbour.

6th.—The present iron pier should be removed and the new pier on wells completed, the communication with the shipping being maintained in the meantime by the north and south piers now under construction.

7th.—The new centre pier on wells being finished, the portions of the north and south piers from B to M and from A to N should be removed.

8th.—The dividing channel ANMB should be dredged out, a portion of the spoil being deposited in the form of a sand-bank, so as to enable railway communication to be established along EC ML and EC NK. It would then be seen whether the dividing channel would keep itself open or could be kept open at a reasonable cost.

31. With these modifications the harbour (complete as to wharfs, sheds, &c., but exclusive of fortifications) may be estimated to cost two millions sterling, inclusive of the amount already sanctioned; and when I say that I cannot recommend further expenditure on the present design unmodified, I can but appeal to the photographs prefacing this report, which speak for themselves. It is with the utmost reductance that I express such an opinion as this. It is not one hastily arrived at, for I have throughout felt the responsibility of permitting in my present capacity the continuance of a work, of which, on engineering grounds alone, as an irresponsible individual I had avowedly disapproved. I have striven to my utmost to do justice to the author of the design under such trying circumstances, and can only regret that my convictions forbid my granting a longer grace.

Madras Harbour considered financially.

32. It is very difficult to say what the want of a harbour costs Madras from a pecuniary point of view. The whole of the lighterage is in the hands of the Masulah boatmen, who have no competitors, and can therefore charge pretty well what they like—a circumstance of which on occasions they are not slow to avail themselves. To quote an instance, during the late famine a boatman has been known to refuse R50 for one trip in anything but dangerous weather, and this for a boat the maximum carrying capacity of which is 3½ tons. General Morgan, who owns extensive tea and cinchona plantations, has furnished particulars of charge, for this class of goods incurred between the rail and the ship, amounting to R24-6 per tons Colonel Thomason made the fullest inquiries into this case, and though no particular reason could be assigned for such extraordinary charges, the correctness of General Morgan's statement stands fairly substantiated. Mr. Mackenzie, of the firm of Messrs. Arbuthnot and Co., supplies the following as the cost of lighterage per ton:—

	R	a.
Piece-goods	2	4
Wines, spirits, and oilman's stores	3	2
Metals	5	10
Timber	12	8

33. The want of a harbour causes two very serious losses to the trade of Madras—one from damage to goods, and the other from theft. It is difficult to form any correct, or even approximately correct, estimate of such losses as these. Mr. Dawson, Chairman of the Trades Association and Head Manager of perhaps the largest store in Madras (Messrs. Oakes and Co.), estimates loss from damage at 20 per cent. of trade profits; and Mr. Winch, of Messrs. Shaw and Winch, Insurance Agents, estimates that 90 per cent. of the loss sustained by Insurance Companies at Madras on account of damage is incurred between ship and shore.

34. The very heavy loss from theft the Trades Association attribute to the Custom House; but with so many openings for thieving as exist at Madras between the ship and the Custom House, this seems a statement which it would be very difficult to prove. It is certain that very heavy blackmail is levied on goods (such as grain) which never enter the Custom House. During the late famine such robberies were, of course, more than usually rife. Mr. Mackenzie, who perhaps is in a better position than most people to form an opinion on the subject, estimates, from what he saw, that during the late famine the loss of grain due to damage and theft at Madras alone could not have been under the value of 6 lakhs of rupees.

35. The Trades Association represented to Colonel Thomason that the Agents at Madras are very often boat-owners, and sometimes lay an embargo on goods in the Custom House until all their boating charges, however exorbitant they may be, are satisfied. In fact, the whole trade of Madras appears to be at the mercy of more than one monopoly besides the boatmen. What these several monopolies are, or how interwoven with each other, it is not easy to say; but the general result of this is that the trade is at present subjected to an avoidable tax sufficient to cover the cost of more than one harbour, however elaborate. The Chamber of Commerce, whose views alone have as yet been laid before Government, are the smallest sufferers of all by the present state of affairs, even if in their capacities of agents, shippers, and creditors to producers, they do not directly profit by it. The parties represented by the Trades Association (shop-keepers, &c.) undoubtedly suffer heavily, and the producers form a third class, who, it is evident, are by far the heaviest losers of all.

36. Colonel Dickens, when Secretary to Government of India, went very closely into the financial aspects of Mr. Parkes' scheme. He estimated that the cost would amount to £776,465, including interest extended over four years. After the fourth year the interest payable would amount to £34,941; but, making arrangements to pay off debt in 40 years, the amount due annually would be £42,196. To this he added for annual repairs and maintenance at 1¼ per cent. £10,650, and present cost of port establishment £4,000, making a total of payments due £56,846. If extinction of debt were not looked for, the payments due would be—

		£
Interest		34,941
Repairs		10,650
Port expenses		4,000
	Total	£49,591

The income he estimated as follows :—

		£
if debt is to be extinguished—		
Shipping, 440,000 tons, @ 8 annas, or 1s.		22,000
220,000 tons goods, @ Re. 1-8, or 3s.		33,000
	Total	£55,000
and if debt is not to be extinguished—		£
Shipping dues as proposed by Chamber of Commerce		20,000
On goods R1-6, whereof R1-4 is at Bombay		30,250
	Total	£50,250

37. The Chamber of Commerce informed Colonel Thomason that there would not be the slightest difficulty in raising an income of £45,000 from the harbour, provided the transhipment to the railway wagons were direct. This estimate is based on a tonnage of under 300,000 tons goods, and a rate of only R1-8 per ton. Supposing 75 lakhs to be the share of expense to be borne by the Port Trust, an annual payment of R4,58,025 in half-yearly instalments to the Imperial Exchequer would in 30 years repay the principal with interest at 4½ per cent. Considering the very heavy tax to which (*vide* paragraph 30) Mr. Mackenzie has shown that the trade of Madras is now subjected owing to existing arrangements, I believe that the R1-8 per ton already conceded by the Madras Chamber of Commerce might easily be raised, if necessary, to R2 per ton, and still leave Madras a large gainer by a good harbour. This would leave an ample margin, not only to cover loss by exchange, but also for the development of the port.

38. In the Proceedings of the Madras Government dated March 17th, 1869, it is stated that at least 382,000 tons of goods are imported or exported at Madras, and it is a safe assumption that with an efficient harbour this will be very largely exceeded. On the other hand, considering all the circumstances here detailed, I have no doubt whatever that for the R1-8 rate suggested by the Chamber of Commerce up to R2-8 might, if necessary, be substituted, and still leave Madras a large gainer.

39. I have already expressed an opinion that a proper harbour for Madras would probably cost £2,000,000. Of the requirements of Madras I cannot but consider that the project now

being carried out falls very far short. It is but an enclosed space of still water, no doubt a very great improvement on what preceded it, as under ordinary circumstances the lighterage, now often a source not only of difficulty, but also of danger, would be very much facilitated; but there is no attempt in this design to dispense with lighterage, and in a financial point of view a comparison (*vide* Appendix VI) between the wharfage rates of Calcutta, which include the cost of receiving, weighing, and delivering, as compared with those of Bombay, where the expense of labour is not represented, will at once show how great a source of revenue is here neglected. The designer from the first has relied on screw pile moorings, though it is a very pronounced opinion amongst seamen that ships so caught in a cyclone must meet with certain destruction, and it is a very open question whether this danger would not be very much aggravated were his last proposal (of mooring the ships fore and aft in rows side by side) carried out. Nor is any shelter against rain, &c., provided, a point on which great stress is laid by the Calcutta merchants. Unquestionably, very much greater security (as well as freedom from lighterage) would be attained by the addition of piers and wharfs (with rails) well provided with strong bollards. This would, as Admiral Bythesea has pointed out, obviate the danger due to the momentum which ships acquire in a gale when riding at screw pile moorings—a momentum which is generally fatal to the stoutest and best of cables, especially when the ship is moored fore and aft. Such piers and wharfs would be provided in the harbour which I contemplate for Madras. Cranes (hydraulic and others) and every appliance to facilitate transhipment should also be covered by my estimate of two millions, but such a harbour would still be incomplete in so far that it would be unprovided with fortifications. An unfortified harbour in such a situation as Madras I should politically regard rather as a source of danger than otherwise. I should therefore consider it imperative not only to provide it with defences, but also fit it in every way to meet naval requirements, which would probably raise its cost to 2½ millions sterling.

40. It now remains to consider the question of the incidence of cost, which I would apportion as follows:—1 million to the Imperial Funds, ¾ million to the Port Trust, and ¾ million to be applied for as a subsidy from the Home Government.

41. In apportioning ⅖ths to the country generally, I am guided by the following considerations: Madras is of itself a place singularly wanting in natural features adapting it to harbour works. These natural disabilities it is not within the resources of a Local Government to overcome, nor is the Local Government responsible for them. At the time that Madras was established, it was the seat of Government, not of a Presidency only, but of what at that time was the Indian Government generally, and on the general Government of the country for this reason, I think, a charge of ⅖ths of the cost might fairly be laid, more especially when we reflect to how great an extent the railway and the general revenues of the empire will be benefited by a successful harbour.

42. Considering the heavy tax which I have already shown falls on the trade of Madras due to its present imperfect arrangements, I have no hesitation in assuming that the Port Trust could easily re-pay the capital assigned to it with 4½ per cent. interest in 30 years.

Madras Harbour considered politically.

43. Regarding the subsidy to be applied for to the Home Government it is necessary that I should treat at some length. To show the value of defended harbours on the eastern coast of India I can but appeal to history. Of this history, at a critical time when the sovereignty in India was the subject of contest between ourselves and the French, an epitome, as bearing on the subject of harbours and of Madras harbour especially, will be found in Appendix V; but the lessons conveyed by history in this case appear to me to be so forcible that I consider no apology necessary for here referring to them. They are—

1st.—That the sovereignty of India was dependent on supremacy in the Eastern seas.

2nd.—That over-confidence in the certainty of this supremacy remaining with them, on the part of the English, resulted in neglect of ordinary precautions, against even a temporary loss of it, and in 1746 led to the capitulation of Madras and, for a time, almost to the extinction of British power in India.

3rd.—That influence on land is inconsistent with loss of prestige at sea.

4th.—That supremacy at sea may at any time be endangered by circumstances over which man has no control. Thus, immediately after the French had captured Madras their fleet, then dominating, was so disabled in a cyclone as to leave it at the mercy of even a very small English squadron, had it been attacked by one. Again, at the final siege of Pondicherry by the English in 1760, which sealed the fate of French empire in the east, the British fleet was by a cyclone similarly placed at the mercy of a comparatively weak enemy, and had even a

small French fleet then appeared and attacked, this siege, all-important to the English, must in all probability have been raised.

5th.—That this supremacy invariably rested with the power which had the nearest safe port as a basis of naval operations. Thus, in 1693 the Dutch masters of the natural harbour of Trincomalee, at once took Pondicherry from the French, and for the time deprived them of their footing in India. Again, the Hooghly being the only safe port on the eastern shore of India, and occupied by the English, gave our fleet the ascendancy over that of the French, whose only safe base of naval operations was in the distant Isle of France; consequently, the appearance of the British fleet off Madras on February 16th, 1759, compelled the French to raise the siege the next day. Finally, the want of a near safe port cost the French their Indian empire, for when Pondicherry fell, the French fleet was absent in the Isle of France.

6th.—That a safe first class harbour centrally situated anywhere on the eastern coast would have been so all-important to either of the contending parties as virtually to decide the contest in their favour. The efficiency of the victor and the safety of the vanquished alike depended on it. Thus, in 1746, la Bourdonnais was virtually defeated by Commodore Peyton; but the British fleet suffered so severely as to be compelled to make for Trincomalee (their nearest harbour of refuge), whilst the French gained their object by getting under the shelter of the guns of Pondicherry, where, owing to the calm weather prevailing at that time of the year (July), they could recruit. The French were, in fact, considering the time of year nearest to a secure base for naval operations, the result of which was that Madras was taken by them from the English. In October 1746, when a cyclone was so disastrous to the French in the Madras roads, immediately after they had captured Madras, they were put to such straits for want of a harbour that they actually had to send their most disabled available ships to Goa to refit, the remainder of the fleet betaking itself to Acheen as the available place of safety during the tempestuous season, nearest to Pondicherry, should the defence of that place demand its services.

7th.—The extreme danger of allowing an enemy to acquire even temporary supremacy at sea. It was the enjoyment of such that enabled the French between 1746 and 1756 to obtain the command of the Dekkan and the whole of the Indian peninsula south of it, and a position so secure that had they but been true to themselves it is difficult to see how any other European power could have supplanted them.

44. Such being the lessons to be learnt from the history of India of the period when we were establishing our footing in it, with how much greater force must they come home to us now? Then the French following the counsels of la Bourdonnais, acquired and made the most of the Isle of France as a base for naval operations to such an extent as to render it necessary for us eventually to wrest it from them. What the French did then it is possible for any European power to attempt now. Should we by any unforeseen circumstances, lose, wholly or temporarily, the supremacy of the seas, there are other islands nearer than the Isle of France which might be taken possession of and used as a menace against ourselves. The remedy in establishing well-defended harbours on our coasts lies, and has since 1760 lain, with ourselves; but what have we done to secure our Indian possessions from attack by sea? Positively nothing beyond the hasty erection of one or two batteries during the pitiful scare of last year, when war appeared imminent with Russia.

45. And still if one *point d'appui* was necessary to secure the supremacy of either nation during the period which I have here reviewed, of how infinitely greater importance is it for us, as regards a want which might at any time endanger our hold on India, to bestir ourselves to meet it in these days of steam, when the altered conditions of warfare (in which success depends so extensively on ample supplies of coal and often on rapidity of coaling above everything) demand, not one, but at least four *points d'appui* on our eastern coast.

46. We have still to see what would, on the combatants, be the effect of a naval action with the ships, guns, torpedoes, and other appliances of the day; but of this we may feel quite sure, that if the wooden ships of yore experienced such difficulty in refitting after a naval engagement of those days, not only the interests of India, but of the whole British empire demand that in these seas our navy should be fully armed against such contingencies, and for this reason I venture to expect a subsidy from the Home Government to the extent at least of $\frac{3}{10}$ths of the eventual cost of the Madras Harbour, whatever it may prove to be, but which I have roughly estimated at $2\frac{1}{2}$ millions sterling.

47. To the other three ports on this coast which we must consider necessary for our safety, I will not further refer here. It is with Madras that we must concern ourselves in the first instance. It is the capital of an important Presidency, the converging point of three railways, and its present defenceless state exposes us to insult at the hands of even one enemy's ship of war that might evade the vigilance of our cruisers.

Moreover, we already stand committed to Madras Harbour, and though I cannot approve of the sanctioned scheme, I feel convinced that any halting or hesitation in the progress of the piers at this stage must insure total failure and the loss of all that has hitherto been spent, the greatest chance of success in this harbour or any modifications of it lying in the speediest possible prosecution of the work.

48. A combination of enemies or other unforeseen circumstances might at any time expose us to the same dangers which so often nearly proved fatal to our forefathers, who founded our Indian empire. Our present relations with our northern neighbours may for a time withdraw our attention from our sea-coast; but if we are ever to yield the dominion of India to any European foe, it is by sea that the foe will come, and it is to the protection of our coasts that we shall have to devote our most earnest attention. Absolute security for our coast commerce is essential to our prestige and security in this country, and to put off to the day when war with a European nation is imminent the measures necessary to obtain this security, is a course too obviously fraught with danger to need further comment.

49. None can deny that it is, in a great measure, to our Indian possessions that we owe our rank among nations, and it is with oureslves that now rests the power and responsibility of making ourselves invulnerable to any foreign aggressors from the sea. Common prudence and the subsequent financial gain to us when defensive measures shall become imperative, alike demand it of us, that by the construction of efficient harbours, placing our vessels of war in these seas at an immeasurable advantage over those of all other nations, we should insure at least the element of safety at all costs; and if we neglect this opportunity, can we expect, or do we deserve to escape, the fate of the strong man armed guarding his treasure, from whom a stronger than he came and took all of which he was possessed?

50. Since the French left us undisputed masters of India, our frontier has steadily been advancing northwards, and now for nearly half a century we have been devoting our attention so exclusively to meet foes in that direction that we have, as it were, completely closed our eyes to possible danger from that seaboard in our rear from which we ourselves effected the conquest of the country. The peace which our southern provinces have so long enjoyed is one which we are too liable to ascribe solely to the less warlike instincts of the inhabitants of those regions, and we have thus lulled ourselves into a false sense of security from which there will some day be a rude awakening if we thus continue to neglect what are but ordinary precautions, and indulge in that spirit of unreadiness which seems inherent in us as a nation, notwithstanding the many rude lessons of the past.

51. We have but to study history to see how great was the importance attached to the possession of Madras by Dupleix, the earliest and ablest of those opposing us in establishing an Eastern empire. We find him constantly diverting the attention of la Bourdonnais and his other lieutenants from all other expeditions against us, however promising they may have been, to the one great object, the possession of Madras. He attained his object by first obtaining the supremacy in these seas, and the immediate result was that we became, for the time being, practically ciphers in the country. What was true for his time is as true, and more so, in ours.

Be the character of the population in the south ever so peaceful, I venture to assert that no defeat that we might sustain at the hands of the Russians in the Peshawur valley or presence of a Russian force under the fortifications—as yet only on paper—of Multan, would prove half so disastrous to us as the successful landing of a hostile force anywhere on the shores of India.

52. Hitherto a single foe (the French) and the elements have been all that we have had to contend against, and how hard was the struggle we all know; but it may be far otherwise in the future. We cannot afford to rest for ever on the laurels of Trafalgar, and whilst we are preparing—I think wisely—to meet our nearest European rivals across the Himalayas, how culpable must be our folly if we neglect precautions against attack from the not only possible, but probable, combination of two or more maritime foes on our coast.

53. If we think for an instant of what war in our time demands, the great importance of artillery, the weight of the guns now in use, the unlimited supplies of ammunition demanded by the arms of precision of the day, the immense mass of matériel, including possibly even locomotives and lines of rail, all of which are essential towards giving in our time one army superiority over another in the field, it must at once be evident that no foreign foe relying on

a long and expensive land carriage could possibly hope to successfully compete with us for the possession of India as long as we maintain secure our base of operations on the coast. The disadvantage at which the aggressor would be placed is so enormous that, notwithstanding constant harassing and intrigue on our northern frontier, the opinion is fully justified that these are but preludes to a grand *coup* hoped for some day, when an alliance with some other great maritime power may enable overwhelming odds to be brought to bear against us on the coast in our rear. There lies our real danger, and Madras is now, as in Dupleix's time, the most vulnerable point on the coast. It is for this reason that I take upon myself the responsibility of urging the expenditure of so large a sum as 2½ millions on Madras Harbour. The supply of what is needed here will not be the work of a day; its cost should therefore be met ungrudgingly, otherwise the day may not be so far distant when we may find ourselves compelled to yield, to an enemy stronger than ourselves, that of which the value cannot be estimated in millions.

CALCUTTA,
18th February 1879.

A. CLARKE.

Report by W. PARKES, Esq., M. INST. C.E., Engineer-in-Chief, Madras Harbour Works, to the Acting Secretary to Government, Public Works Department, on the present state and prospects of the Madras Harbour Works,—No. 7 W, dated Madras, 25th February 1879.

Having, since my arival in Madras on the 12th January last, submitted to the Government three reports, the first dated 24th January, on the expenditure on the Harbour Works up to 31st December last, the second dated 15th February, on the diversion of the town sewage from the harbour, and the third dated this day, on the changes of the shore line north and south of the harbour, it now only remains for me, before my departure, to submit to you the result of the personal observations I have made during my stay as to the present state and prospect of the work.

2. One main object of my present visit was to have the opportunity of witnessing the actual progress of the works during the most favourable season. It is only by this means that I am enabled to judge of the efficiency of the organisation in its several parts, and how far the prospects which I have from time to time submitted to the Government are likely to be realized.

3. It is not to be expected that a work of this magnitude can be carried out in strict accordance with a previously prepared specification. To insist upon this would be to discard the advantages of the practical local experience gained as the work progresses. But it is at the same time desirable to keep in view not only the ultimate object of the works, but certain broad features of the means by which that object is to be attained, and not to be hastily led away from these by the apparent advantages offered by some modification which may at the same time introduce evils likely to escape observation in any but a comprehensive review of the whole question.

4. It is in the settlement of such questions as these that the occasional personal communication between the Superintendent as the possessor of the greater amount of local information and experience and myself as the original organiser of the works is important. Unless, however, the result of our conferences be to introduce any important change in the arrangements of the work, they afford little material for special report to the Government.

5. I have only to report, therefore, that after having made a careful examination of all departments of the work, I am satisfied that they are all in a fairly efficient state. I do not consider that the full attainable speed of work has ever yet been reached, and probably it never will be maintained for any great length of time, for the several parts of the organisation which have to be brought into work together are more numerous and complicated than is at first sight apparent, and the failure of any one will affect the whole.

6. It is only since my arrival at Madras that one important operation has been brought into full action, *viz.*, the deposit of stone for the rubble base from the steam hopper barges *Salisbury* and *Hobart*, though the latter has been temporarily disabled and is now under repair. It is satisfactory to find that these vessels are quite equal to the work which was expected of them, although our better acquaintance with the local circumstances has led us to adopt a plan of loading them different from that originally contemplated.

7. As the work advances into deeper water a much larger proportion of rubble stone will be required for a given length of pier, and their full powers will be taxed to keep it supplied, but on the other hand the shelter afforded by the piers will be more complete and the work therefore more regular. When the water is fairly calm, the vessels lie alongside the face of the concrete blocks easily, and are loaded by coolies carrying stone from the Madras Railway trucks standing on the pier itself.

8. The supply of stone from the Ambatoor quarries on which we must depend for the great bulk of our rubble base is in the hands of the most competent contractor in the neighbourhood on terms which, though not excessive, will give him no excuse for not pushing on the work with energy, and I am bound to say that so far no complaints have been made. The present rate of supply, however, about 1,120 tons per day will have to be increased by 30 per cent.; but there is a large area of quarry ground as yet untouched.

9. The Madras Railway Company also perform their part of the work in the transport of the stone with fair regularity.

10. The rubble base for the south pier is mainly formed by the deposit from the steam hoppers, but the top has to be levelled by stone carried out by cargo boats or thrown in from the top of the *Titan* or from the pier itself. This stone is more conveniently supplied from Pallavaram and brought by the South Indian Railway, but at the present time great complaints are made of the irregularity of the stone trains on this line, and this irregularity has latterly retarded the progress of the south pier by 25 per cent. I hope, however, that the evil is only temporary.

11. This is only an example of the kind of friction which, acting on one part or another of the machine, retards its motion in a way that cannot be calculated on. If there were nothing to do but to set blocks as fast as they can be set, the rate of progress would exceed any anticipations that have been expressed in any quarter. As the natural obstacles caused by sea disturbance and accumulation of sand are surmounted, those due to inevitable imperfections of organisation become more prominent. Some allowance must be made for these to the end of the work, but as it progresses, the weak parts of the organisation will be strengthened, and the rate of progress be less and less retarded.

12. The north pier is now 1,431 feet from the commencement of the block work, and there remains 2,430 feet to complete it. The south pier is 923 feet, and there remains 3,080 feet. Apart from interruptions 200 feet per month is a rate of advance quite attainable, but, allowing 150 feet as the average rate for ten months of the year, and entire stoppage for two, it would result that the north pier may be completed in September 1880, and the south in March 1881.

13. There is one suggested possible obstacle to the realisation of this prospect of completion as to which it is desirable that I should offer some remarks. It is said that we have had no experience of the effect of such a sea as is raised within the actual limits of a cyclone, and that this may turn out to be very destructive. It would be presumptuous to deny that such an event may produce unexpected result, but I think there are circumstances which tend to reduce limits of uncertainty to within what they would appear to be at first sight. First, the difference in the destructive power of a cyclone sea and that of the propagated swell which we have experienced on more than one occasion, and notably in December last, must not be measured by the difference in the destructive power of the cyclone itself with its furious wind and torrents of rain on shipping and objects on shore, and that of a simple rolling swell in the roads, and a heavy surf on the beach. Wind and rain can have no direct effect on the harbour piers, however much they may intensify the apparently irresistible fray of a storm.

14. It is certain that the sea disturbance is propagated more quickly, and to a greater distance from the centre of a cyclone than the atmospheric disturbance, and therefore the only conclusion that can be drawn is that the propagated swell has a force more nearly equal to that of the central sea disturbance than is the case in regard to the atmospheric disturbance.

15. Again, it is the experience of all engineers of marine works in England that the swell preceding, or propagated from, a storm at some distance is more destructive than the sea raised under the direct influence of the wind, and it is a fair inference that the same rule would hold good in India.

16. Further, there is a large margin of stability in the works as carried out with the full depth of foundation, 24 feet below mean sea level, over any force they have yet had to resist, either here or elsewhere. The slight disturbances that have taken place where this depth was not attained confirmed former experience of the value of deep foundations. This, and the size of the blocks, and the mode of packing them together, are elements of strength which do not exist in any of the sea works, the damage to which furnishes the most useful lessons.

17. On the whole, therefore, while fully admitting that a repetition of one of the great historical cyclones may exhibit results of an unexpected kind, I am bound to contend that such a lesson is required to teach us where we can apply additional strength. So far as the present experience of engineers goes, we are armed at all points. There is one case on record, that of Wick in the north of Scotland, where a mass of masonry, 45 feet wide, was bodily displaced by the sea, and the sea has in that case so far remained the acknowledged victor. But the case is

entirely exceptional, and to take it as a precedent would be to condemn many works of well tested stability. The Madras piers are only 24 feet wide, but the difference of conditions in other respects is more than a balance for the less width.

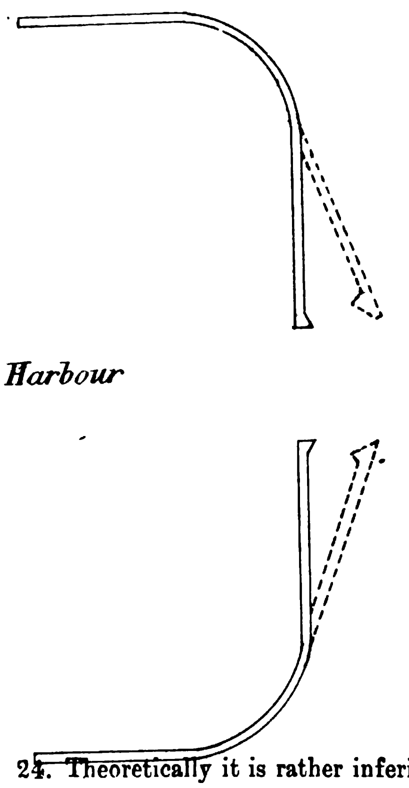
18. I think this is the only suggested cause of failure in the completion of the works which has not already been negatived by the event. The accumulation of sand over the foundations, which was so troublesome at the north pier in 1877, was repeated in 1878 at the south pier, but its entire absence at the north pier in the latter year was a good ground for the anticipation that it would be also only temporary at the south pier. It will, however, be a satisfaction to find that there is no return of the trouble in the approaching monsoon.

19. The accumulation extended a considerable distance from the pier, and had intruded upon the available deep water in November last to the extent of six acres beyond the 4-fathom line of the previous February. More recent soundings show some recovery of depth, and there will probably be more. I expect, however, that some loss of harbour space must be accepted as permanent, but I have no fear that it will be added to now that the pier has advanced into a greater depth of water.

20. Assuming, then, that the completion of the harbour at no distant date is an event that may be anticipated, I would now beg to bring to notice of Government some questions which will shortly be pressing for settlement.

21. The first of these is the form of the seaward side of the harbour and the entrance. This is a question which I have always looked upon as desirable to be kept open till near the time when a final decision was necessary, and in the interim I have availed myself of such opportunities as presented themselves for collecting evidence as to the merits of different forms.

22. The result is that I am rather disposed to favour a change of the design to the form shown in red on the accompanying tracing and by dotted lines in the marginal sketch. The main argument in favour of the originally proposed straight eastern front is that if the present harbour should be followed by a series of similar basins ranged along the coast, a series of re-entering angles would be formed in which converging waves would be concentrated to an inconvenient extent. On the other hand, the projecting entrance, though more in accordance with precedent, and undoubtedly more convenient for the entrance of vessels under sail, did not appear to have so much superiority for steamers.



23. I find, however, that Commanders of steamers would generally prefer the projecting entrance as leading the cross current off from acting on the after part of a long ship, while the fore part is in still water and with little way on her; also, it would give a greater space to bring up in without danger of fouling ships at moorings. Captain Taylor, the Master Attendant, prefers this form.

24. Theoretically it is rather inferior to the original line for calming the interior of the harbour, but I do not think the difference would be appreciable in practice. The future difficulty of the re-entering angles may, I think, be left to be dealt with when it arises, and thus both these points may fairly give way to the immediate nautical advantage of the modified form. The cost will not be appreciably affected by the change, as the width of entrance is proposed to be increased to 550 feet, so as to compensate for the increased length of the two sides of the triangle.

25. I would, therefore, beg to recommend this modification for consideration. An immediate final decision is not necessary if the Government should think it desirable to obtain more nautical evidence upon the question.

26. Another question is even more urgently requiring early action, *viz.*, that of providing fixed moorings for ships in the new harbour. These will be absolutely necessary before the harbour can be fairly utilised, because only a very limited number of ships could be accommodated swinging to their own anchors. There is little doubt that in the north-east monsoon of 1880-81, if moorings are laid down under the lee of the north pier, ships may be secured to

them. For this purpose they should be fixed in the previous fair season of January and February.

27. I have conferred with Captain Taylor on this subject, and we are agreed upon an arrangement which will, I think, give the maximum of accommodation and security at a minimum cost. He will bring the matter before the Government more suitably than I can, and I have therefore left the nautical part of the question in his hands.

28. With regard to its engineering and financial aspects, however, I may state that the cost will be about £40,000. The exact amount may be affected by such modifications of detail as Captain Taylor may recommend. This is not included in my estimate for the harbour works, and it will probably be treated as a distinct financial question, and a charge made on *shipping* to cover the interest on first cost and maintenance independent of the harbour dues on *cargo* inwards and outwards.

29. But I would venture to raise the question whether the funds may not be considered to be already in the hands of the Government by a re-appropriation of the savings already effected on the estimate for the harbour works. The Government had sanctioned £20,000 over and above my estimate for purposes for which it has not been, and never will be required; and a further £20,000 has, as shown in my letter dated 24th January, been saved upon my estimate on works already completed. Such excesses as have occurred on other items are well under the 10 per cent. on actual past expenditure estimated for contingencies, so that if these £40,000 were transferred to the charge for moorings, the harbour works expenditure up to the present time would still be within the estimate.

30. The screw moorings, cables, and buoys will have to be procured from England, so that it will be seen that in order to ensure their being laid down this time next year, early action should be taken.

31. In my letter to the Under Secretary of State, dated 18th October 1878, I raised the question of considering the details of the mode in which the harbour revenue should be raised. My only concern with this as engineer was to see that any proposals were consistent with the engineering and physical features of the future harbour. I found on arrival at Madras that the subject was already under the consideration of some leading members of the Chamber of Commerce, to whom I gave what information I could relating to my own share of the question. I believe that proposals to Government may be expected as the result of this movement. It may perhaps be as well to state that I am no party to the proposals themselves, having only assisted in giving them a practical form.

32. I would beg to conclude by stating generally my belief that this important undertaking is now in a state which gives promise of an early and successful accomplishment.

Minute by His Excellency Lord Lytton, Viceroy and Governor General of India,—dated 22nd July 1879.

The importance of its subject, the novelty of its suggestions, and the pressure of other claims on the careful attention it deserves, have prevented me from sooner circulating, with this record of my own conclusions on the questions raised in it, the accompanying Minute by Sir A. Clarke on the Madras Harbour Works. I must observe, however, that Sir Andrew Clarke's Minute, though dated the 18th of February 1879, was only placed in my hands by my Hon'ble colleague about three weeks ago.

2. It is stated in the 31st para. of that Minute that, with the modifications proposed by Sir A. Clarke, these works would cost two millions sterling, exclusive of fortifications and naval requirements, which my Hon'ble colleague considers essential to their utility; and which, if carried out, will increase the total estimated cost of his project to two millions and a half.

3. This project involves many considerations other than those of an engineering character; but I do not now examine or discuss them, because the cost of it appears to me quite prohibitory of an experiment in what is admitted to be "an entirely new engineering problem." The Government of India could not commit itself to a scheme on which there may still, perhaps, be something to say from Mr. Parkes' side of the question; nor could it finally discard Mr. Parkes's hitherto unsuccessful plan, until the subject has been further considered by engineers of the widest experience in this branch of work.

See para. 24, Sir A. Clarke's Minute.

4. The main points for discussion by the experts appear to be—

(i) whether it is necessary to alter Mr. Parkes' design at all in its main features;

(ii) if so, whether the modifications proposed are likely to be effective.

Para. 30.

If these two questions be each affirmatively answered, I cannot at present see how we are to carry out a scheme involving at least four times the cost of the original proposals; and, in that case, I should, on the whole, prefer the abandonment of the work already done at an expenditure, I understand, of some £270,000 to the investment of further capital in a scheme involving an estimated expenditure of £2,500,000, or, excluding the defensive works, of £2,000,000. A harbour at Madras, however well made or useful it might be, is not, in my judgment, worth such a price as this.

5. From the further discussion of the matter, however, the question of defence must I think, be altogether omitted. To defend such a harbour effectually, it would, I presume, be necessary to construct outline forts in advance of the works, in deep water, and at an enormous expense. If the batteries were placed on the works, any approach of an enemy's ship sufficiently close to enable them to come into action with our batteries, would also enable them to inflict heavy damage, if not total destruction, on the shipping in the harbour. For the protection of the shipping, therefore, we should have, in any case, to trust, as we do now, to the efficiency of our cruisers.

6. For the prevention, or repulse, of a hostile landing, Madras has at present many great advantages, natural and artificial. It is a difficult place to land at in any circumstances; and, if a landing were effected, we could, by means of the railways converging at the port (railways constructed since the days of Dupleix), concentrate a force there strong enough to render quite impossible any permanent lodgment. The mere fact, as noted in the 47th para. of Sir A. Clarke's Minute, that Madras is the converging point of three railways, indicates the means of concentrating upon it, if necessary, the whole of our available land forces; and these obvious facilities for the immediate concentration of our military strength in conjunction with our naval power, assign to the political aspect of the question a character essentially different in every single particular to the conditions of it a hundred and thirty years ago.

7. The sum of money it is now proposed to expend on the construction and fortification of a harbour at Madras appears to me out of all proportion to the risk we run from the chance of invasion or foreign aggression on that somewhat inhospitable part of our sea-board. It is equally, I think, out of proportion to the value of the trade at Madras; even if there were not other more important sea-ports, to the defence and improvement of which our available funds should be first devoted. I should not be prepared to encourage any heavy expenditure on the defences of Madras until the defence of Aden, Bombay, and Karachee is adequately provided for.

8. Sir A. Clarke proposes that we should ask the Home Government to give us a subsidy of £750,000 towards the enlarged works; and he bases this proposal on the assumption of their great political value to the British empire in general. It will be seen from the foregoing remarks that I do not share Sir A. Clarke's opinions on this part of the question. I certainly could not address to Her Majesty's Government any proposal of the kind. I fear I must add that I cannot conceive any circumstances in which it would be proper to throw on the Indian tax-payer the heavy burden of providing for the cost of the project put forward by my Hon'ble colleague in his accompanying Minute: and it is quite clear that such a burden could not be borne by Madras alone.

9. If we cannot get a good harbour at Madras by the scheme suggested by Mr. Parkes, and at a cost not seriously exceeding his estimates, the only reasonable course is, in my opinion, to abandon the project altogether, even at the sacrifice of all that has been already spent, on this ill-considered and abortive undertaking.

10. I think that a full report should be obtained as speedily as possible from the Government of Madras as to the present prospects, in the opinion of the best local authorities, of Mr. Parkes' scheme, and the probable effect of the modifications of it proposed by my Hon'ble Colleague.

11. Without, however, awaiting the receipt of this report, the papers should be at once referred to the Secretary of State, with a despatch in the sense of the foregoing remarks. The question that remains to be decided with the least possible delay is, whether the continued execution of Mr. Parkes' present plan, without any serious modification of it, affords a sufficient prospect of providing Madras with a safe and durable harbour at a cost not exceeding Mr. Parkes' estimate. This question is not an ordinary engineering question; it involves engineering problems of a very special character on which there is in India little or no practical professional experience. Our highest and most authoritative adviser, Sir A. Clarke, whose personal experience of harbour engineering is, I believe, extensive, has carefully examined, and emphatically condemned, Mr. Parkes' project. On this point I have little doubt that the opinion of the best Madras engineers will be found in complete accordance with that of our Hon'ble colleague: and although on such a point their experience is probably more

limited, and their opinion certainly less authoritative, than his, it is, I think, desirable that it should be officially submitted to us. On the other hand, the alternative project suggested by our Hon'ble colleague involves an expenditure which, as already stated, I consider to be out of all proportion to the value of the object in view, and which the Government of India is not in a position to incur. Consequently, the project of a Madras Harbour must be altogether abandoned, or else carried out at a cost not greatly exceeding Mr. Parkes' present estimates. On the objections to the further prosecution of this plan, which experience thus far has suggested, Mr. Parkes is of course entitled to be heard. But he is now in England. I therefore think that the proposed despatch should request the Secretary of State,—who is in a position to refer directly, not only to Mr. Parkes, but also to the most eminent English authorities on harbour engineering,—to decide the engineering question raised by the ill success of the works now being carried out in accordance with Mr. Parkes' plans.

12. Pending such a decision we are, unfortunately, compelled to continue upon the Madras Harbour Works an expenditure which may hereafter prove to have been infructuous and wholly wasteful. It is, therefore, I conceive, expedient that no further time should be lost in transferring this question from the region of indefinite speculation to a practical point susceptible of speedy settlement.

13. In the meantime the work on the north and south piers should be continued on its present basis.

14. Sir Andrew Clarke's Minute should, of course, accompany the proposed Despatch to the Secretary of State.

22nd July 1879. LYTTON.

Minute by the Hon'ble Sir A. J. Arbuthnot on the Madras Harbour Works,—dated 5th August 1879.

I agree with His Excellency the Governor General in thinking that it is impossible to incur such an expenditure as is considered by our colleague, Sir Andrew Clarke, to be necessary for the construction of an efficient harbour, and I see no reason to question the correctness of our colleague's opinion as to the inutility of the works now in progress upon Mr. Parkes' plan. The right course, in my opinion, is to recommend to the Secretary of State that the works be at once stopped, and that no further expenditure be incurred on them except such as may be necessary to prevent their interfering with the traffic and salubrity of the Port. I deprecate any further reference either to English or Madras engineers. Our colleague is a very competent authority upon this subject, and I think we may safely act upon his opinion as to the inutility, and worse, of the works now in progress.

To continue the works pending consultations with English and Madras engineers, which will probably occupy many months, and at the rate at which the Madras Government now transact business, possibly years, will be simply to throw good money into the sea for no earthly purpose as far as I can understand.

Despatch from the Government of India, to the Secretary of State for India, forwarding above munites, and recommending further prosecution of Madras Harbour Work be abandoned,—No. 11, dated 15th August 1879.

By our despatch, Public Works Department, No. 133, dated 15th December 1877, we reported to your Lordship's predecessor that we had arranged that our colleague Sir Andrew Clarke should shortly visit Madras, for the purpose of examining the works in progress in connection with the harbour there, and thereafter advising us as to the course that should be, eventually pursued. We also explained that in the meantime, and to prepare the way for the examination above spoken of, we had sent to Madras an experienced officer of Royal Engineers, charged with the duty of collecting certain information and conducting certain observations in accordance with instructions issued to him by our Hon'ble colleague.

2. A report of the results of the inspection above referred to, with the opinion of our Government upon its contents generally, was asked for by your Lordship's despatch No. 55 (Public Works), dated 26th September last.

3. We have now the honour to submit a copy of a minute by Sir Andrew Clarke, and of another which has been recorded by the Governor-General, as well as a copy of the instructions which we have sent to the Madras Government in the matter. A minute by Sir Alexander Arbuthnot, concurred in by Mr. Stokes, is also enclosed.

4. Your Lordship has been made aware by the despatches from the Government of Madras, No. 9, dated the 11th March, and No. 33, dated the 11th June last, that a modification in the form of the seaward side and entrance of the Madras Harbour has been proposed, and

that the nautical authorities who have been consulted by the Local Government prefer it to the original design. Your Lordship has further been asked to obtain the highest professional advice upon the question.

5. The proposals now brought forward by Sir Andrew Clarke will be found in the 30th paragraph of his Minute. They involve changes of a much wider kind; and the estimates now submitted show that the cost of the harbour, when completed, will be enormously in excess of the sums which have hitherto been regarded as the probable ultimate outlay. It is stated in the 31st paragraph of Sir Andrew Clarke's minute that, with the modifications proposed, and the conveniences necessary to all harbour projects, the works would cost two millions sterling, exclusive of fortifications and naval requirements, which our Hon'ble colleague considers essential to the utility of any harbour scheme for Madras; and which, if carried out, would increase the total estimated cost of the project to two millions and a half.

6. With the exception of the proposals, *firstly,* to place an entrance in both the northern and southern arms, leaving unbroken the eastern, or seaward break-water, but extending it some 900 feet to the eastward, and *secondly,* to modify the design by introducing a dividing channel, our Hon'ble colleague considers that all these proposals are common to the two schemes, namely, his own and that of Mr. Parkes; and that apparently the construction of wharfs has always been contemplated, although no estimate of their cost has hitherto been prepared. In comparing, therefore, the cost of the original design with that of the design as modified by him, our Hon'ble collegue considers that this fact must be borne in mind.

7. In submitting, for your Lordship's orders, these proposals of our Hon'ble colleague, we desire to record our very decided opinion that, if a good harbour cannot be secured for Madras at a cost, inclusive of past outlay, not much in excess of Mr. Parkes' original estimate, all intention of proceeding with the project should be abandoned without delay; and that future attention should be confined to ascertaining what use, if any, can be made of the work already accomplished at a cost to the State of about twenty-seven lakhs of rupees.

8. In deference to the wishes of the Madras Government, and in order not to prevent the extension of the south pier into deep water beyond the bank of moving sand, we have placed no hindrance on the progress of the work; but it is clearly most desirable, in order to avoid further waste of money, that your Lordship should decide, on the advice of the highest authority procurable in England, what further measures should be taken respecting a work which is now represented to as likely to require for the satisfactory completion of it, an outlay out of all proportion to its value for commercial or naval purposes.

Memorandum by W. PARKES, ESQ., on Sir Andrew Clarke's minutes,—dated 6th November 1879.

I have read and carefully considered the report of Sir Andrew Clarke on the above harbour (herewith returned), and in accordance with your letter of the 11th October, beg to submit the following observations.

2. Sir Andrew Clarke's comments on my plan may be conveniently considered under the following heads:—

1.—The sand difficulty.
2.—The question of entrance.
3.—The question of mooring.
4.—The provision of wharfs and quays.
5.—The sanitary question.

The Sand Difficulty.

3. The point at issue between Sir Andrew Clarke and myself may be expressed in a very few words. My conclusion was from the first, and still is, that supplementary works will at some future time be required to prevent the advance of sand from destroying the harbour, but that the period at which this will become necessary is so distant that it need not at present be taken into account.*

4. Sir Andrew Clarke disputes the validity of the data on which I base the latter part of this conclusion, and maintains that the destruction of the harbour by the advance of sand is sufficiently imminent to justify and demand immediate preventive measures, involving extensive changes of my plan. Into the merits of his proposal for meeting the evil I am precluded by your instructions from entering.

* To show that this does not impose any very serious burden on posterity, I may mention that whatever the length of time may be it may be *doubled* by the extension of the South Pier seaward for a length of 1,000 feet, at a cost of 80,000*l.*

5. I believe I shall best comply with what I understand to be the wishes of the Government by carrying out an intention which I had formed before I received Sir Andrew Clarke's report, of submitting to you a review of the whole sand question from its commencement to what I now feel justified in calling its termination. It is a subjecet not only of great importance to this particular undertaking, but also of much interest from a professional and scientific point of view.

6. The area of discussion is very much narrowed by Sir Andrew Clarke's admission of what I consider to be the one great principle, which is the key of the whole question. It is one for which I have contended from the first, though, in consequence of the special circumstances under which I made my original report, it is rather tacitly assumed than positively asserted therein. That principle is that the force by which the sand is disturbed and transported is that of the *waves*, and not of the *currents*, and that its movements are confined to a belt bounded by the shore on one side and by a line approximating to the 4-fathom contour on the other. Outside this there is no important movement. So far, Sir Andrew Clarke and myself are agreed.

7. It is important to bear in mind that Sir Andrew Clarke's report is dated February 1879, that his personal inspection took place a year earlier, and that the investigations of Lieutenant-Colonel Thomason, R.E., on the results of which he appears to place much reliance, were made in the latter part of 1877. Much had occurred, since even the most recent of these dates, to throw light upon the question.

8. In order that the bearing of the several stages of the review I am about to present upon the question at issue may be seen, it will be desirable to describe somewhat more in detail the conclusions which were formed as to the action of the waves upon the sand, originally from analogy and hypothetical considerations, but which, as I hope to show as I proceed, have been gradually strengthened, and are now fully confirmed by the result.

9. It is well known that the waves in the two monsoons approach the shore from different directions, approximately north-east and south-east, each obliquely transverse to the general line of the shore. The first and main movement of the particles of sand lifted from the bottom by the waves must obviously be in the same direction as that of the particles of water which has lifted them, and this must be either in the same direction as the wave itself is moving, or the exactly opposite direction, without any tendency to a diversion to the right or the left so long as the wave has an unimpeded onward movement. But when this movement is met by the shelving bottom, a portion of the particles of sand-laden water are diverted right or left according to the direction of the obliquity, and thus an *alongshore* movement is communicated to the sand. At first the proportion of this movement is small, but as the rolling wave advances towards the shore into still shallower water, the degree of obstruction increases, and the alongshore component of the movement increases with it until, where the wave makes its final break on the beach, the onward movement is completely arrested, and the final result upon the particles of sand carried by it is a transport for a certain distance *alongshore*.

10. It directly follows from this, *first*, that the alongshore movement is very much greater close to shore than it is further out; and, *second*, that the movement in the outer part of the area of disturbance, whether great or small in itself, has a large component of transverse movement, and a small one of alongshore movement. The importance of making a distinction between these two movements arises from the fact that the alongshore movement is directly arrested by the piers, and so far as the movement in one direction in one monsoon is not balanced by that in the other direction in the other monsoon, the effect will be cumulative from year to year. The transverse movement, on the other hand, will not be interfered with by the piers, and the seasonal changes will continue to balance one another as heretofore.

11. I have to request, then, that in following the statement I am about to submit of the movements of the sand from the commencement of the works to the present time, these two principles may be kept in view, so that they may be compared with the facts as the latter are successively presented.

12. The accompanying drawing presents in one view the effects produced by the four successive south-west monsoons of 1876, 1877, 1878, and 1879. The portions of the works coloured red show the advances made in the several half-years from 31st March to 30th September; the portions coloured burnt sienna, the above water accumulations; and those coloured blue, the portions washed away during the same intervals.

13. *Monsoon of 1876.*—The north surf bank was begun in January 1876, and by the end of March it had advanced some little distance into the sea. The sand began to accumulate on its southern side soon afterwards, and as the bank advanced, the coast line followed at some distance in the rear, till both reached the positions shown by the end of September. The depth of water in which the bank was made of course increased as it advanced seaward, but the sandy bottom was much disturbed by the local action of the waves around the end of

the bank, and moreover anything like accurate survey was impracticable in the surf. The depth, however, immediately in front of the bank was about 6 feet at mean tide in March, and 10 to 12 feet in September. The advance of the shore ceased in September, the erosive action of the northerly seas set in in October, and before the return of the south-west monsoon in 1877, the shore line was cut back to the extent shown.

14. There was, no doubt, a good deal of sand disturbance within, and possibly somewhat outside the belt of surf, besides that which resulted in the accumulation of the shore shown on the plan, but it was beyond the range of possible survey, and our knowledge of it rests upon such evidence as the unusual extension of the surf in one direction or another, the "bumping" of a masula boat in an unaccustomed place, or a discolouration of the water previously unnoticed. These facts are suggestive of some unusual disturbances, but are of too vague a character to justify any conclusion as to their nature. What is certain about the disturbances is that they had entirely disappeared before the following March, and all that remained was an advance of the line of beach in front of the town of rather more than 100 feet.

15. The triangular accumulation and its partial removal, as shown on the plan, was, however, a definite addition to our materials for estimating the *amount* of sand movement due to the alternate southerly and northerly alongshore wave action. Its *completeness* as evidence depends on the degree of reliance which may be placed on the first of the two principles enunciated in para. 10, and which as yet rested entirely on hypothetical considerations. My own belief was, and is, that it is a legitimate deduction from admitted principles, and that it might fairly be concluded that the amount of sand which passed the line of the pier, but would have been arrested by the pier itself had it been in existence, was so small in comparison with that actually arrested as to be properly disregarded. A calculation made upon this assumption showed that at the same annual rate of accumulation it would require 50 years for the 4 fathom line to reach the sea-face of the harbour, and if it were further assumed, as the plan shows, to be well within the mark, that half the accumulation under the southerly seas is removed by the northerly seas, the period would be extended to 100 years. But even if this be not admitted, and a substantial allowance be claimed for sand which passed freely, and is therefore not shown by the area of accumulation, a very considerable one might be made without so reducing the "life" of the harbour as to trench upon my contention that the means of extending it may be left to posterity. Up to 1876, however, my reliance was on a hypothesis based on abstract reasoning. I hope to show that it may now be based on *fact*.

16. *Monsoon of 1877.*—The south surf bank was commenced early in the year, but was not so far advanced, when the movement of sand from the southward began, as the north bank had been at the corresponding period of the previous year. The total amount of accumulation is shown on the plan. The quantity intercepted by the south bank itself is obviously less than that intercepted in the previous year by the north bank, but a considerable quantity appears to have been also intercepted by the north bank, which must, therefore, have passed the south bank. The aggregate of the two coloured areas is not very different from the one area of 1876.

17. Here we have an undoubted case of the sand passing one groyne and being intercepted by a second. If the second groyne had not existed, the sand would have passed freely along the beach to the northward, and all evidence of its having passed the first groyne would have been destroyed. If, in such a case, a calculation of the "life" of the harbour had been based on the supposition that the quantity intercepted by the groyne was the whole quantity in motion, the conclusion would have been obviously false, and if the facts so far stated stood alone, they would go far to invalidate the conclusion which I drew from the amount of sand arrested in 1876, and which I assumed did represent the whole quantity in motion.

18. There are other facts, however, which materially affect the question. The results shown by the coloured areas are those of the whole six months. If we compare those of the first three months with those of the last three months, we shall find a remarkable contrast. I have shown on the same drawing the shore line of the 30th June 1877, and it will be seen that while to the south of the south pier this line is in the middle of the area of accumulation *between the piers*, it nearly coincides with the line of 30th September. Thus, whatever sand did pass, passed before the end of June; after that date the whole was intercepted. The cause of this is obvious. In the early part of the season the bank was but little in advance of the advancing shore line, but in June it made a considerable start, and passed the outer boundary of alongshore movement. Now, the north bank was, throughout the monsoon of 1876, in a stage analogous to that of the south bank *after* June 1877 rather than *before* that date, so that my conclusion that the whole of the sand was, in the former year, intercepted, though based at the time on hypothetical considerations, is fully confirmed by the subsequent

experience of the effect of the south bank. I may mention that since June 1877 there has been no permanent or general advance of the beach within harbour limits.

19. While these changes of the coast line were going on in consequence of the advance of the south surf bank, the "sand difficulty" was manifesting itself in another form at the north pier. After the 30th September 1876 the outer end of the bank was flattened down by the action of the northerly seas, so as to form a good foundation for the concrete blocks, and by the end of March 1877 a length of nearly 300 feet had been built, carrying the end of the pier to a point about 100 feet in advance of that at which the end of the rubble bank stood in September, and where the depth of water was about 16 feet.

20. Some disturbance of the bottom following the change in the direction of the prevailing seas was quite anticipated, though it was uncertain what form such disturbance would take. A warning from me to that effect to the Superintendent reached Madras a few days after the first symptoms of the disturbance had appeared on the 31st March. The disturbance took the form of an accumulation of sand around the end of the pier, covering the foundation and preventing blocks being placed in advance. Its result is seen in the small amount of progress made in the following six months.

21. The accumulation being entirely under water, and almost entirely under broken water, the details of its form and extent could only be very imperfectly ascertained. It appeared liable to changes, sometimes disappearing for a day or two, and then returning, but these changes could not be satisfactorily connected with any apparent causes. The sand over the rubble foundation, which was itself 2 to 3 feet above the original surface of the sand, varied from 4 to 8 feet, increasing generally as the season advanced. Its extent was not great, varying from 50 to 100 feet to seaward of the end of the block work, and to something like the same extent on either side, but in consequence of the impossibility of taking soundings through the breaking surf, the records of the most critical parts are wanting. There is a good deal of evidence of what this accumulation *was not*, but the evidence of what it *was* is very imperfect.

22. The questions to be most carefully considered were these: 1st, Was this disturbance part of an alongshore movement which would be arrested by the formation of a solid pier across its course, and thus tend to an annually increasing accumulation? 2nd, Was it an effect which would follow the advance of the pier into deeper water?

23. With reference to the first of these questions, there were some facts suggestive of a negative reply. It was not a mere extension of the ordinary surf movement, for, although the waves broke heavily on this accumulation itself, there was an interval of unbroken water between it and the surf which was constantly breaking on the shore. Also, it began before there was any accumulation on the coast line in April, and it continued after the erosion of the coast line began in October. It was, therefore, clearly independent of the alongshore movement on the coast, and, if so, it would be quite a gratuitous assumption that it had any alongshore component at all.

24. With reference to the second question, it seemed sufficient reply that the location of the disturbance was well within the area in which disturbance had been anticipated.

25. On the whole, therefore, the conclusion seemed safe that nothing had occurred in 1877 at variance with the second principle suggested in para. 10, *viz.*, "that the movement in the outer part of the area of disturbance, whether great or small in itself, has a large component of transverse movement and a small one of alongshore movement." My confidence in this was further strengthened by the remarkable fact of the absolute arrest of the alongshore movement by the south surf bank after June.

26. Such were the circumstances which appeared to me to justify the expression of a confident expectation that the difficulties of 1877 were of a transitory kind. I was not surprised, however, that to those who examined the matter less closely my confidence should appear misplaced. In the face of the repeated predictions that "the sand difficulty" would be fatal to the success of a harbour at Madras, the assertion that an obstruction by sand which had brought the work almost to a standstill for six months was not *the* sand difficulty, was one which seemed almost to court incredulity. It was at this time that Sir Andrew Clarke's special investigations were undertaken.

27. It was not till January 1878 that the obstruction of sand in the foundations of the north pier was finally overcome. It has not, however, since re-appeared in any form, and the soundings taken from time to time show that beyond the 4 fathom line there is no disturbance of the bottom whatever. So far as the north pier is concerned, the sand difficulty ended in 1877.

28. At the south pier the setting of concrete blocks was begun in November 1877, and by the end of March 1878 a length of 423 feet had been built, placing the end in a depth of

3½ fathoms. During the same interval the northerly seas had cut away the coast south of the harbour for a width of 100 feet, while within harbour limits it had cut away from the northern half and added to the southern half, leaving a line parallel to that of the previous March, but 100 feet further seaward, this width of 100 feet representing the amount accumulated between March and June of 1877.

29. *Monsoon of 1878.*—The accumulation to the south of the south pier began in April, as in previous years, and by the end of June the coast line had advanced 350 feet. The works of the pier had been in abeyance during almost the whole of those three months, from causes independent of the sand difficulty. As a matter of fact, the foundations were then clear of sand, and it is possible that if the blockwork had been advanced during those three months, the sand difficulty would have terminated at this stage. While the abrupt end of the pier stood in a depth of 3½ fathoms, there was no apparent disturbance of the bottom, but the advancing beach on the south pushed out the foot of its slopes, and before work was resumed the depth was so decreased as to establish the conditions necessary for disturbance. Then followed a state of things similar in its main features to that at the north pier in the previous year, but with some important differences which have added something to our knowledge.

30. The sand gathered around the end of the pier into a heap probably greater than that of 1877, and in September and October, when it was at its maximum, it was surveyed with tolerable precision. The result of the survey is shown by the blue contour lines on the plan of 1878.

31. The summit of the accumulation was at F, where the original depth being 21 feet, was reduced to 5½ feet. Around this summit the successive contours are arranged in irregular circles or parts of circles, and the limits of the accumulation may be approximately traced by the approach of the lines to a direction parallel with the coast.

32. The evidence presented by this accumulation supplements in a remarkable manner that presented by the similar accumulation at the north pier in the previous year. The accumulation of 1877 clearly indicated the existence of a cause independent of that which produces the surf on the shore. The times of its commencement and its cessation, and the interval of unbroken water, are proof of this. In the case of 1878 evidence on this point is imperfect. The accumulation was apparently indirectly due to the advance of the coast line. That it was not merely an extension of the shore surf disturbance, however, is proved by the fact that, though there was no interval in the surf, there was a depression in the level of the sand in a position corresponding to the interval of 1877. But the weight of evidence on this point rests with the case of 1877, though the latter carries a strong presumption to that of 1878.

33. In 1877, on the other hand, direct evidence as to the disposal of the sand is entirely wanting. It might have been carried away northward beyond the range of observation. In 1878 evidence on this point is complete. The form of the accumulation is that which would naturally be assumed in a case where the motive power had spent itself. But beyond this, if any sand had been carried further to the northward, it must have been caught in the angle between the shore and the north pier, as it was previous to July 1877, but none was found there.

34. On the contrary, as is clearly shown on the plan, the beach line between the pier rather retreated than advanced during the south-west monsoon. This, however, is only apparent. During the previous north-east monsoon there had been an apparent advance, due probably to a steepening of the slope under water. During the south-west monsoon it was simply flattened again, and the line of September 1878 is almost exactly coincident with that of September 1877.

35. The accumulation at the end of the south pier in 1878 retarded the advance of the block work, though not so much as in the previous year at the north pier. The work was advanced 148 feet between June and September by sinking the blocks through the sand. The obstruction was entirely past in the following January, and by the end of March 1879 a further length of 539 feet had been set, bringing the end of the pier into depth of rather more than 5 fathoms.

36. During the same six months the coast line was cut away south of the pier for a width of 300 feet, while between the piers it was cut away in the northern half, and accumulated to an equal extent in the southern half.

37. *Monsoon of 1879.*—The history of the sand question in this year is a very short one. "Difficulty" there has been none. Not a grain of sand has shown itself at the foundations of either pier, and the depths at the foot of the slopes of the newly-made rubble banks are practically identical with those found before the work was begun, so that there has been no disturbance of the bottom. The anticipated accumulation has taken place in the angle between the shore and the south pier; but, instead of being increased by the quantity of sand, which, according to the theory I am combating, would have passed the end of the pier if it had not

been extended, it is materially less than in previous years. The accumulation of 1878 has been flattened down, and its present form is shown by the contours on the plan of 1879. What the total amount of accumulation has been is shown by a comparison of the blue contours with the original depths shown in black figures. The coast line within harbour limits has remained entirely unaltered.

38. It would, no doubt, be satisfactory if I could give a more complete explanation of the accumulations of sand which encumbered the ends of the piers in 1877 and 1878, but it should be no cause of surprise that I am unable to do so. Nothing is more complex than wave action, nothing more unaccountable than its effects. In these cases all the results were under water, and generally under broken water, so that the evidence is most fragmentary. The absence of any disturbance in the two years that the north pier, and the one year that the south pier, have been extended into deep water, would certainly point to the conclusion that an abrupt obstruction standing in a critical depth of water induces special wave disturbances, but beyond this all is mere speculation. One thing, however, is, I think, abundantly clear, and that is that the disturbances, however troublesome and disheartening at the time, had no connection whatever with the regular and comparatively well understood alongshore movement, which continued its independent course in the still shallower water close to the shore.

39. I would beg to direct attention to a comparison of the accumulation of one south-west monsoon (1876) at the north pier, with the cumulative effect of two complete years, 1877 and 1878, each with its two monsoons, S. W. and N. E., and the one S. W. monsoon of 1879, The total effect in reference to a line parallel with the coast is not very different in the two cases.

40. Now, the accumulation of 1876 is objected to as a measure of the probable "life" of the harbour on the ground that it does not represent the whole, or nearly the whole, of the sand in a state of movement alongshore. The result cf 1877 is admittedly useless for this purpose, but in 1878 the arrest of sand must have been more nearly complete than in 1876; and in 1879 it was absolutely complete, yet the whole sand arrested in these three years has failed to produce an accumulation very much greater than that of the one year to which exception is taken as being only a partial arrest. This fact alone is, I think, a complete justification of my assumption of the substantial completeness of the arrest in 1876.

41. The present state of things does not give a good basis for a new calculation of the life of the harbour. A better one will be given when the coming north-east monsoon has produced its effect, when we shall have the net cumulative result of three complete years; but it is already pretty obvious that the conclusion is not likely to be less favourable than that based on the result of 1876 alone.

42. This concludes my review of "the sand difficulty," and I trust I have shown satisfactorily that it is no longer a ground for anxiety. I think that this statement of the whole case will render unnecessary any detailed examination of Sir Andrew Clarke's argument, which is only an expression of certain doubts which at an earlier stage were quite legitimate, but which ought now to be completely set at rest by the event. Nor does it seem necessary to enter upon any defence of the positions I took in the earlier stages of the undertaking with regard to some questions then debateable. An imputation of recklessness in drawing conclusions will be hardly entertained against me by the authorities of the India Office, and I have therefore passed over some points of which the discussion could only take the form of a defence against such a charge. I am confident that my case will not be permitted to be damaged by my reticence in these two respects.

I now proceed to the other questions raised by Sir Andrew Clarke.

The question of Entrance.

43. Sir Andrew Clarke is evidently unaware that the question of providing one or two entrances to the harbour was the subject of a full discussion in 1874, to which the few sentences in my report of 1873 were merely preliminary.

44. The then Chief Engineer of the Madras Presidency, Colonel (now Major-General) Walker, R.E., had suggested two entrances, and, although I thought it right to place my reasons for a contrary opinion on record, there was an understanding that I was to consult with nautical authorities on the subject, and report the result to the Government of Madras. At the same time the Government of Madras requested the Secretary of State to obtain the opinion of the Elder Brethren of the Trinity House on the point.

45. I applied to the Directors of the Peninsular and Oriental and the British India Companies for the opinions of some of their commanders, and I also applied to Mr. J. J. Franklin, R.N., late Secretary of the Marine Board, Madras, who had been introduced to me by the late Sir Henry Mortgomery as the best nautical authority connected with the port.

The results of these applications were rendered in some measure abortive, from the fact of some of the authorities consulted having mistaken the nature of the question, and furnished their opinions on the comparative merits of a detached break-water—a scheme for which had been lately under discussion, and a close harbour.

46. The following is a *résumé* of the replies obtained :—

The Elder Brethren of the Trinity House expressed a preference for a break-water parallel with the shore, 9,000 feet long, and did not enter into the question of one or two entrances.

Mr. Franklin gave a decided preference to the single entrance.

Captain Atkinson, Superintendent of the British India Steam Navigation Company at Calcutta, also decidedly preferred the single entrance.

Captain Gaby, Peninsular and Oriental Company, considered the harbour as shown would in great measure satisfy the requirements, and preferred it to a break-water, but did not suggest the two entrances as an improvement.

Captain Rennoldson, Peninsular and Oriental Company, thought " Mr. Parkes' plan, with one entrance, a good one."

Captain Barlow, Peninsular and Oriental Company, was strongly in favour of a harbour rather than a break-water, approved generally of my plan, and "did not think anything of the difficulties of ingress and egress."

Captain Stewart, Peninsular and Oriental Company, thought the enclosed harbour with single entrance superior to a break-water, and saw no difficulties for ships to enter or depart. He suggested an extension of the northern jetty to cover the entrance.

Captain Black, (the late) Superintendent, Peninsular and Oriental Company, Southampton, was decidedly in favour of a detached break-water, but admitted the value of a harbour for landing and shipping cargoes. He did not discuss the question of one or two entrances.

Captain Henry, (the late) Superintendent, Peninsular and Oriental Company, Bombay, recommended a greater area of harbour, and two entrances, but added, " If these two alterations would not interfere with the project financially, I am of opinion that they would be improvements, but should they so increase the cost of construction as to necessitate an extra charge on the shipping or trade using the port, then I am of opinion that it would be preferable to make the harbour as you propose." (I may mention that the extra cost of the two entrances, so arranged as to give the same internal capacity and calming effect as the plan with one entrance, would be about 80,000*l*.)

47. Besides these opinions in writing, which were forwarded to the Government of Madras, I had many opportunities of obtaining valuable opinions in conversation with practical nautical men. I came to the conclusion that, while some difference of opinion did exist, the preferences on the one side or the other were not strong, and certainly not strong enough on the side of two entrances to warrant the extra cost, and interference with plans for possible future extensions.

48. I know of nothing which has occurred in the last five years to alter the conditions of the question except the continued rapid substitution of steamers for sailing vessels in the trade, which has weakened the case in favour of the two entrances.

49. The modification of the single entrance lately proposed, unanimously approved by the nautical authorities consulted, and since sanctioned by the Government of Madras, removes some of the objections to the entrance as originally designed.

50. I may add that the rubble base for the north pier has already been deposited, and the superstructure commenced across the suggested site for the northern entrance, and that for the south pier has reached the site of the southern entrance. I hope no idea of altering the present plan will be entertained, but, if it should be, I believe, the cheapest and quickest mode of making the alteration would be to finish the piers in the lines at present laid out, and then remove those portions of them where it is desired to form entrances.

Question of Mooring.

51. Sir Andrew Clarke's criticisms on my proposals for moorings are based on grounds which are entirely obsolete. The plan of mooring appended to my Report of 1873 was put forward to meet a question raised at the time, but was never intended as a practical suggestion. I was in this difficulty at Madras. There was virtually no nautical authority with whom I could co-operate to devise a system of moorings, the then Master Attendant being a strong opponent of the whole scheme of a harbour. It was therefore necessary to submit such a plan as the future responsible nautical authority could amend in one of the two directions which are described in my report, but as to which of the two were preferable I

knew there was a difference of opinion among seamen. I had seen reason for congratulating myself on having left this question open, for before I left India I had opportunities of consulting with the two highest nautical authorities in the country, and one preferred one alternative and the other preferred the other, each holding his opinion in a rather decided manner.

52. The question therefore remained in abeyance till nine months ago, when, in co-operation with the present Master Attendant, Captain Taylor, I submitted a system of moorings combining in great measure the advantages of both plans. This proposal has been approved with great unanimity, and would, I have reason to believe, have received the formal sanction of the Government of Madras before this, but for the obstruction caused by the appearance of Sir Andrew Clarke's report. It is not liable to the objections urged by practical seamen against the proposal (certainly never made under any circumstances by me) of mooring ships head and stern in a cyclone. It leaves ships perfectly at liberty at such times either to put to sea or to swing freely head to wind to all points of the compass within the harbour, at the option of the commander and of the Marine authorities. I would again emphatically assert, what I have always maintained, that there ought to be nothing in the system of moorings, or in the port regulations, which could interfere with the full freedom of every commander to put to sea on the threatening of a cyclone. Whether time and experience may not induce a greater confidence in the security of the screw mooring is quite another question, and one to which the question of the advantages of the harbour for commercial purposes has but little relation.

The provision of Wharfs and Quays.

53. The absence of this from my scheme is made a prominent ground of complaint by Sir Andrew Clarke, but five years' experience of the requirements of the trade of Madras has not led me to give greater urgency to this demand. About 45,000*l*. per annum is spent upon the landing and shipping of goods. Of this, two-thirds will be saved by the simple provision of a still-water shore line, and the greater part of this saving will be absorbed by the interest on the outlay for providing this. What remains will not leave much to meet the cost of deep-water walls or jetties, hydraulic cranes, and other expensive appliances of a first-class port. The call for such things may come in time, but it will be some years hence, and under conditions very different from the present. What is at present wanted is quick and certain despatch, and that will be best secured by the use of large cargo boats, which can come along each side of the ship if necessary, plying to cheap shallow-water jetties run out from the shore. The cost of these will be small and self-remunerative. It is still a question whether they should be provided at the charge of Government or by private enterprise.

54. There will, no doubt, be an early demand for one or two deep-water quay berths with powerful cranes, for landing and shipping articles of exceptional size and weight, but special cranage fees will meet the cost of these, and the means of providing them has always, been under consideration.

55. On the whole I have failed to disocver that Sir Andrew Clarke has suggested any want that has not already received such consideration as its urgency seemed to demand, though I must admit that my ideas of the mode of meeting them are generally conceived on a more moderate scale than his.

The Sanitary Question.

56. This received full consideration at a very early stage of my preliminary investigation. It divides itself into two heads—1*st*, the interception of all house and surface drainage from the harbour; 2*nd*, the prevention of pollution by the shipping within the harbour.

57. It had been my original intention to include a proposal for the first in my design, but as I was informed that my object would be effected by a plan of general town drainage, then almost decided upon, I felt relieved of the necessity. This plan, however, fell through, and the interception of all drainage from the harbour was then at once admitted as a necessity, and a fair charge against the undertaking. Works for carrying out the object are now in progress.

58. With regard to the prevention of pollution by the shipping, that also is an object to be kept in view, but a necessary preliminary to devising measures for carrying it out is to obtain data on which to judge of the amount of nuisance to be dealt with. There are many worse cases than that of Madras is likely to be in which the evil is admitted, but the remedy neglected. At present I am not aware of any place that can be taken as an example of meeting the evil satisfactorily, and it may be that it will be necessary to create a precedent at Madras. But the problem is not a difficult one to solve, and its immediate solution is not

urgent. I may say, however, that the ideas which have been put forward of inducing a current of water through the harbour appear to me to be chimerical. The only natural mechanical purifying power available is the tide, which will change abcut one-tenth of the enclosed water twice a day. Whatever this fails to effect must be provided for by stringent port regulation.

59. Before concluding this communication I wish to correct some errors as to matters of fact into which Sir Andrew Clarke has fallen.

60. In the note at the foot of the photograph No. 2, taken 5th April 1879, it is said: —" Advance of foreshore and consequent loss of accommodation within harbour is here evident." The advance here alluded to is that immediately to the northward of the south pier, which, as explained in para. 36 *ante*, is balanced by a retreat to an equal extent immediately to the southward of the north pier. This is also shown in Sir Andrew Clarke's own plan (Plate III), which gives the comparative shore lines in September 1878 and January 1879. There has, as a matter of fact, been no advance of the shore line within the harbour since June 1877.

61. In para. 25 Sir Andrew Clarke says, " The acreage has already been so far encroached upon that, in the opinion of some seamen, it is already a question whether some of the long steamers of the Ducal Line could, without running ashore, enter the harbour of reduced acreage." There is no such reduction of acreage as Sir Andrew Clarke assumes, except in the extreme south-east corner, which was affected by the accumulation of 1878, a part in which no ship ever yet anchored. The effect of this accumulation on the system of moorings now before the Government will be that, out of 18 berths provided for large ships, the depth will be reduced in one from 4 to 2½ fathoms, and in another from 4 to 3 fathoms, thus making them available only for light ships. With regard to the danger of ships running ashore, the 4 fathom line is 2,400 feet, or more than six ships' lengths from the entrance. Three ships' lengths is generally considered sufficient to bring up in, on entering a harbour. In arranging the moorings rather more than 1,600 feet, or more than four lengths of the longest ships, is allowed to the nearest buoys.

Despatch from the Secretary of State for India, to the Government of India, forwarding, with remarks, the above memorandum by Mr. Parkes,—No. 5, dated 29th January 1880.

I have had under consideration in Council your Excellency's letter, No. 89, dated the 15th of August last, on the subject of the harbour works now in progress at Madras, together with the minutes on the same subject, by your Excellency and certain of your colleagues, which are transmitted with that letter.

2. One of the first steps taken by me on the receipt of this letter was the communication of Sir Andrew Clarke's Report on the works to Mr. Parkes. Mr. Parkes has, as your Excellency will perceive from the enclosure to this despatch,* replied at considerable length to the objections urged against his scheme, and the conclusion to which I have been led, after carefully weighing the representations on both sides, is that to stop the works in question after allowing them to proceed so far would be a step for which sufficient warrant has not been furnished by any new facts adduced.

* Report, dated 6th November 1879.

3. There does not seem to be more reason now than there was when the object was originally sanctioned, for doubting whether the plan of Mr. Parkes will secure, at a cost not exceeding the estimate, the kind and degree of protection which has been all along contemplated, or for considering the difficulties greater than were recognized from the beginning. And seeing that more than half the estimated cost has already been expended, much stronger grounds than have been adduced ought to be shown, in order to justify the complete sacrifice of past outlay which would result from stoppage of operations at their present stage. Under these circumstances, I consider that no practical advantage would be gained by consulting any fresh engineering authority.

Memorandum by Colonel R. N. Sankey, R.E., Chief Engineer, Govt. of Madras, P. W. Dept., and Captain J. H. Taylor, R.E., Master Attendant, on the Colombo Harbour Works, 1881.

With reference to G. O., No. 657 W., dated 11th March 1881, authorising our visiting the Colombo Harbour Works, we desire to record very briefly the results of our inspection of the same on the 5th and 6th ultimo.

2. In the first place we would submit for perusal the documents noted in the margin and a map showing the present condition of the works and the various proposals for their completion which have been submitted for the decision of the Ceylon Government.

1. Proceedings of the Ceylon Legislative Council, Session 1880 (discussion on the Colombo Harbour question, pages 32 to 40.
2. Further correspondence relative to the Colombo Harbour Works, with Report by Sir John Coode, dated 16th June 1880.
3. General plan of the Colombo Harbour showing the several schemes proposed.
4. Three cross-sections of the work; also one of the Madras Break-water.

3. An inspection of the map will show that in the scheme recommended by Sir John Coode the main break-water would be carried from its root along the line of the Isaure rock for a distance of 4,200 feet, where would be placed the harbour mouth, 600 feet wide, in 40 feet of water, facing the north-west. Beyond this would be the north arm, 2,500 feet long, having a general direction of south-west by west.

4. The Surveyor-General's (Colonel Fyer's, R.E.,) scheme follows the same line as regards the main break-water, but is made to curve round to the north-east, and is carried out further than in Sir John Coode's scheme, so as to dispense with the necessity for the so-called north arm.

5. The third scheme proposed as a *pis aller* need not be adverted to as having apparently been rejected by all authorities.

6. Somewhat more than half the main break-water, as proposed by Sir John Coode, has already been completed, and the whole will, it is supposed, be out of hand in about four years more.

7. Considering the high authorities ranged in both sides of the discussion and our own want of local knowledge, it would be out of place to express any opinion as to the merits of questions at issue. At the same time we feel no difficulty in saying that the work as hitherto carried out is most creditable both to the projector, Sir John Coode, and to the officer who has hitherto executed the work, Mr. Kyle.

8. What chiefly struck us in reference to the work already carried out was, not only the massive section given to the break-water, which commences with more than double* the width of that at Madras, there being, first on the seaface two bonded concrete blocks side by side, each 12 feet across; second, an interval of the same width packed with rubble stone; and, lastly, on the harbour face a wall consisting of single concrete blocks of the same dimensions, in all 50 feet in width, while, as the Government are aware, the Madras work has only a wall standing on the rubble base, consisting of two concrete blocks and measuring, in the aggregate, 24 at top, 28 at bottom in thickness.

9. In addition, we found that from the action of the sea during the south-west monsoon it is held to be necessary to further protect the seaface by tipping in masses of *pierre perdue*, the majority of the stone so used (very hard granite) being of large size, the intention being apparently to establish all along the face an outer rough-stone revetment, which, when settled down, shall rise to about 12 feet below M.S.L.

10. It is needless for us to say that the work thus carried out presents a very different section to the Madras work (see annexed sections comparing the two works).

11. Its massiveness is, no doubt, in great degree necessitated—first, by the way in which the general line of the break-water faces perpendicularly in direction of the seas during the south-west monsoon, to the full swing of which it is exposed; and, second, to the violent† manner in which the seas apparently break on the Isaure rock, along the line of which the work is carried.

12. The two cases are not therefore altogether comparable, and it would not by any means follow that the difference in section indicates any radical difference in power of resisting the forces to which the break-waters are respectively exposed.

13. At the same time we think it would not be out of place, now that the Madras work has been advanced so far towards completion (without, however, during its construction, having had to sustain the shock of any very heavy gale or cyclone sea) to ask the projector Mr. Parkes to explain his own views as to the difference in section in the two works.

14. It would no doubt be satisfactory to Government and the public if he were distinctly to affirm his opinion that the different circumstances of the Madras work are such as to enable him to pronounce definitely his conviction as to its stability, not only in regard to the shocks

* The root seawall from the Battenbury bastion advances 665 feet and meets the junction line of the root and pier; from this, seawards, the 50 feet wall advances 1,327 feet, after which commences the 34 feet wall of three blocks, with no intermediate span.

† Mr. Kyle mentioned the fact that, after the previous south-west monsoon, the outer portion of the break-water, 470 feet in length, 34 feet broad, was found to have been gradually pressed inwards by the action of the sea to the extent of 15 inches at the outer end—a remarkable testimony to the continuous force of the sea during four months monsoon weather.

to be sustained by the sea in a maximum cyclone, but also in case of a heavy ship being at such time driven against the break-waters as now constructed.

15. Viewing the extra protection now being given, as above noted, to the Colombo work by means of rough stone on the seaface, it would be desirable to know whether some similar operation might not be wanted, particularly along the exposed portions, especially the northern arm of the Madras work.

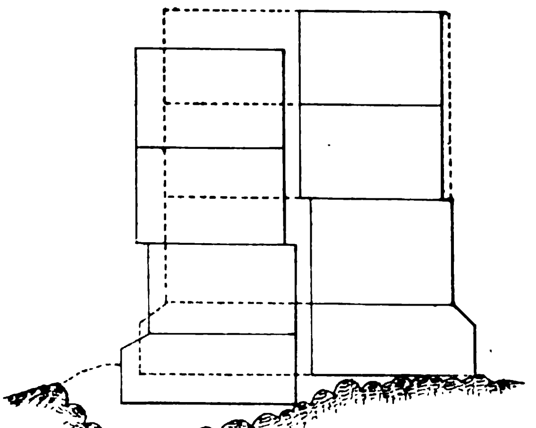
16. It is perhaps as well that this point should receive Mr. Parkes' attention, as it will be seen by the observations* (extract given for ready reference in the footnote, from his report of the 14th January 1881, printed with G.O. of 31st idem, No. 256 W.) that during the rough weather of the 21st November the upper portion of the rubble base, having, as reported, been scooped out by the sea-action at the end of the north pier, the two outermost concrete blocks, which had shortly before been set, "dropped down" about 3 feet, and would in all probability have fallen had it not been for special precautionary arrangements previously adopted by the Superintendent of the Works, thus showing that under certain conditions the sea-movement extends down to the rubble base, and that too in weather which, although rough, cannot be said to compare with what may be looked for in a cyclone of great intensity.

17. The inquiry now raised appears to us to be the more important as Mr. Parkes in his concluding words, as quoted, does not expressly guarantee the work against the effects of an extreme cyclone, and further, as Major-General Walker, when Chief Engineer, purposely inserted an extra item of two lakhs of rupees for the rubble base with the view of affording additional protection to the work.

18. In conclusion, there is one other point to which, as it has a very direct bearing on all the harbour schemes along our coasts, we desire to draw the attention of Government, and that is the depth of water which, with the present class of large vessels, it is considered essential to secure at the entrances of all such.

19. In Colonel Fyer's proposed scheme modifying Sir John Coode's, the end of the break-water is taken out to 35 feet depth of water; but, as will be observed, the latter, in the following extract from his report on the Colombo harbour, dated 16th June 1880, does not

* "This sea is also especially noteworthy, because by it for the first time have some blocks, fairly set at the proper depth and on a clean rubble foundation, been disturbed, thus affording some direct evidence of the limits of stability of the work. At the north pier the rush of water round the end was so violent as to scoop out a hole in the rubble at the foot of the blocks into which the end blocks dropped down about 3 feet, being at the same time laterally displaced slightly, as shown in sketch. The iron clamps by which they were attached to the third row behind them were not broken and that row and the one intermediate between them were not disturbed.



"The most obvious effect of the sea on the completed portion of the north pier was to strip off the railway from the top, but this effect only extended for the length built since the last heavy sea in November 1879. In the older portions it was not disturbed. The cause of this difference was apparent on examination of the blocks themselves. They had evidently been subjected to a very severe shaking, for the surfaces were found to be abraded by rubbing against one another to such an extent as in some cases to form indentations 4 inches deep. To produce this result the whole structure must have been in a state of violent vibration, and this would break the connection between the tops of the individual blocks and the contiguous rigid railway laid upon them. When the block work has once been subjected to this vibrating action it becomes consolidated and rigid, and the railways maintain their connection with it. The sea does not appear to have caused any general subsidence.

"Reverting to the subsidence of the end blocks, it may be well to point out how this bears on the sufficiency of the design for the permanent pier head. The weak points in the temporary termination are evidently the following: —

"*1st.*—Rubble stone at 22 feet below the surface is not proof against the scour of the wave rushing round the abrupt end of the pier.

"*2nd.*—The abruptness of the end increases the force of the scour.

3rd.—The blocks have a hold of only 4 feet 6 inches, their own thickness in the solid work.

"Now, though the exact form of the whole of the permanent pier head is not yet determined, yet some features have long been settled on :—

"*1st.*—The depth of the foundation of the blocks on the rubble will be 28 feet instead of 22.

"*2nd.*—There will be no sharp corners to aggravate the scour, the corners being formed of blocks in the quadrant of a circle 12 feet radius.

"*3rd.*—All the blocks exposed to the end between these curved angle blocks will be set as 'headers,' with their ends instead of their sides exposed, so as to have a hold in the work of 12 feet instead of 4½ feet.

"With these additional elements of stability it is clear that the permanent pier head will be proof against a much heavier sea than the temporary one."

look upon this as sufficient, *viz.*, "in a case like the present, and more epecially where there is such a small rise of tide, provision should certainly be made to admit of the safe entry and exit of the heaviest draughted ships *at low water;* thus the depth of 40 feet provided for in design B may be regarded as the ruling working depth in the entrance. If it is desired that the new harbour should be adapted for the reception either for coaling or other purposes of the ships of Her Majesty's navy during the south-west monsoon, it will be necessary that a depth of not less than 40 feet shall be available in the entrance. The draft of an ironclad may be put down at 28 feet, and of the largest of the merchant steamers at 23 feet. Adding 8 feet for "scend" or vertical rise and fall of a ship during the south-west monsoon, and allowing 4 feet for clearance under the keel when at the lowest level, these figures give 40 feet as the depth required in the entrance for the safe passage of the ironclad and 35 feet for the "merchant steamer."

20. It will be in the recollection of Government that during the discussion on the subject of the conditions which it was considered essential to secure in regard to the proposed harbour at Cochin, the Master Attendant gave it as his opinion that the break-waters should at least be carried out into 30 feet water.

21. It is thus satisfactory to find that experts of the high standing of Sir John Coode exact even a greater depth, and as this matter has an immediate bearing on the question to be solved at Pámban, which forms the subject of our next report, we have thought it desirable to place his opinion prominently on record for the information of Government.

(Signed) J. H. TAYLOR, *Captain, R.N.R.*,
Master Attendant.

(Signed) R. H. SANKEY, *Col., R.E.*,
Chief Engineer, P. W. D.

2nd May 1881.

Report by W. PARKES, Esq., C.E., on the width of the break-water adopted at Madras and the necessity for any special protection of it,—23 Abingdon Street, dated 4th August 1881.

Madras Harbour.

In the G.O. No 1436 W. of the 8th June 1881, I am requested to offer such observations as I may desire on a memorandum signed by the Master Attendant and the Chief Engineer, on the harbour works now in course of construction at Colombo from the designs of Sir John Coode.

2. In the remarks I am about to submit I shall think it right to abstain as far as possible from any comparison of the conditions to be met at Colombo and at Madras, or of the mode in which the engineers of the two works have, in the independent exercise of their judgment, endeavoured to meet them. I shall simply address myself to the very legitimate questions raised:—

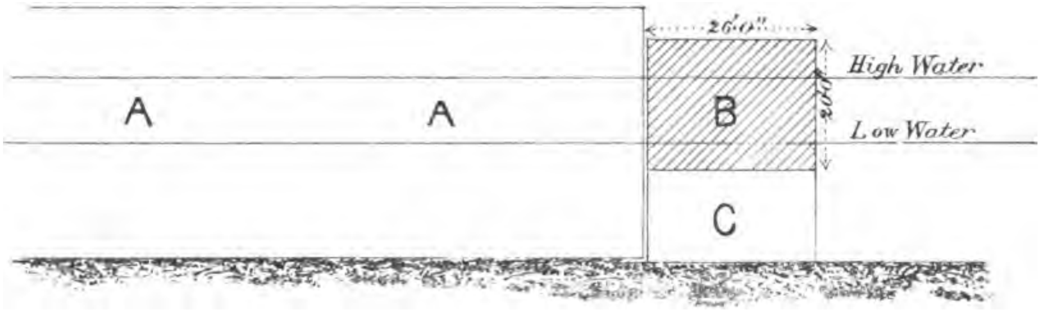
1st.—As to the propriety of the width of break-water adopted at Madras.

2nd.—As to the necessity for any special projection by large stone of the surface of the rubble base beyond the walls of concrete blocks.

3. The determination of the proper width for a break-water is one of those questions which cannot be based upon any definite data. It is seldom possible to ascertain the maximum height of the waves at any given site, and even where that is known there is no definite knowledge as to the relation between that height and the force which the heaviest waves may exert in any direction. Again, our knowledge is very imperfect as to the way in which the waves themselves are acted upon by the works intended to withstand them. Break-waters of some forms act upon the waves on their first contact in such a way as to intensify their destructive force upon another portion of the work, and thus these works require to be more massive than would otherwise be necessary. Thus, theory is almost entirely at fault in this question.

4. Practice and experience are not much more satisfactory than theory. There are numerous examples of damage by wave action, but these are with very few exceptions due to imperfections which are quite independent of the width of the whole work. The damage generally begins by the loosening of an individual block of stone or concrete. This forms the commencement of a breach, which is widened by each successive wave, and the work is destroyed in detail. Up to 1872 I do not think there is any case on record of a portion of a pier or break-water being moved as a whole mass by the force of the waves.

5. In December 1872, however, such a case occurred at Wick, in the north of Scotland. It is described in the Minutes of the Institution of Civil Engineers by Mr. David Stevenson, the Engineer of the work.



Elevation

Plan

The above sketch roughly represents the work. A A is a pier of very massive masonry of the usual kind. The shaded portion B is a mass of concrete and masonry, 26 feet long, 20 feet high, averaging 46 feet wide, and weighing 1,350 tons. During a heavy storm in December 1872 this mass was moved bodily from its position and deposited entire on the rubble inside the pier. After this protection had been removed the sea attacked the main body of the pier from the exposed end and destroyed it in detail in the usual manner for a length of 150 feet.

6. The pier was subsequently restored, and a new monolith placed at its end, of the same length and breadth as the former one, but secured by bolts to the portion C, making the whole mass 2,500 tons. This in its turn was carried away as its predecessor had been.

7. It will be easily understood that these extraordinary occurrences were matters of deep interest to engineers connected with marine works. When the particulars became known to me the break-water at Kurrachee, 24 feet wide, had been completed, and those at Madras of the same width had been sanctioned for execution. I carefully reviewed the bases of my own conclusions with this new fact before me, but I soon found that an indiscriminating application of the lesson would condemn, not only these works, but many others which have stood the test of many years' experience, and I ultimately saw no reason to alter my own designs.

8. An occurrence at Kurrachee which took place six months after the earlier one at Wick added another important fact to our data. It may be remembered that the first few hundred feet of the Manora break-water suffered repeatedly from the failure of the foundations, which caused the displacement of several blocks. The most serious case of this involved the complete overthrow of the harbour side wall for a length of about 80 feet, leaving the sea side wall, consisting of a single row of blocks, standing 12 feet wide, without any support. This stood perfectly throughout the remainder of the monsoon. This direct proof that 24 feet was more than enough at Kurrachee seemed to outweigh any indirect conclusion from the unprecedented occurrence at Wick.

9. I should mention that the force of sea at Wick is acknowledged to be most exceptional. A competent observer estimated the height of the waves at 42 feet from hollow to crest. The highest wave measured at Kurrachee was 15 feet. None have been recently measured at Madras, but a former Master Attendant, Captain Biden, estimated the maximum height at 10 feet. The most extreme alarmist therefore could hardly suggest the necessity of adopting the Wick proportions at either of these places.

10. I may state, however, that the only portions of the Madras work which can be subject to a destructive force similar in kind to that at Wick, though less in degree, are the pier heads. These, for other reasons than stability, will have dimensions considerably in excess of those at Wick. The bodies of the piers themselves will be 45 feet wide, and this width will be further supported by a return towards the shore 75 feet long. It is therefore, I think, impossible to imagine them liable to any such damage.

11. There is, however, another effect of the sea, in consequence of which some engineers have considered it desirable to increase the width of break-waters. There is no doubt that under a heavy sea the whole superstructure is subjected to a violent vibration, especially if it rests on a yielding foundation. This vibration would undoubtedly be lessened by increasing the total mass to be vibrated. But the necessity for this depends on the effect produced by the vibration. A mass of bonded masonry has its coherence entirely destroyed by such an action. The effect is like that of an earthquake. I have seen such work almost reduced to the appearance of ruins. But the effect on the unbonded work of the same dimensions at Kurrachee and Madras is very different. A heavy sea upon the last built lengths of either of those works has uniformly served to consolidate them and improve their condition, and the second sea had little or no effect. This I consider a most important result of our experience at Kurrachee and Madras, and I am happy to say that it is about to be further tested by the adoption of the unbonded system in other places by two of the most eminent Marine engineers of the day, who are converts to it.

12. Such are the grounds upon which I consider that a narrower break-water is justifiable at Madras than has been considered desirable in some other places. But I must repeat that there are no definite data upon which the proper width can be determined. An experience of ten years at Kurrachee and of five years at Madras without the slightest indication of weakness in a 24-feet break-water has no doubt increased my expectation of its absolute stability, but in dealing with such a force as the sea I am not disposed to accept the invitation "to pronounce definitely my conviction" on the subject. When the long-threatened cyclone visits Madras it will no doubt teach a lesson. I will not speculate whether the alarmists will be taught that their fears were unfounded, or that a more or less unexpected weak point will be detected in the work. All I feel justified in saying at present is that I see no reason for thinking that the break-waters would be strengthened by adding to their width, nor can I at present suggest any other way in which they can be made more secure.

13. With respect to the second question, that of covering the surface of the fore-shore with large stones, I would remark that where such covering is resorted to, it is generally with the view of giving additional security to the foundations of the vertical sea-face. But such security may be given in other ways—

1st.—By founding the walls at a great depth below water.

2nd.—By using blocks which have a great depth of bed and consequent hold in the wall.

3rd.—By reducing to a minimum the height of the wall above water, so that the waves may expand themselves over the top of the break-water instead of falling, with accelerated force on their recoil, down the sea-face.

14. In these particulars the design of the Madras break-waters is carried further than in any other work with which I am acquainted, and I intended these particular features to be carried so far as to make us quite independent of the use of large rough stones. These are more than usually difficult to be got at Madras, and the execution of the work was materially simplified by dispensing with their use. The deep foundations may be viewed as a substitute for them, and I have every reason to be satisfied with the result.

15. In special cases, however, the principle is adopted at Madras. Thus, near the commencement of the north pier, where the original depth of water did not admit of deep foundations, the shallow foundations are protected most effectually by a foreshore of large concrete blocks, and it is further intended, as an extra precaution to place some large blocks at the feet of the pier head walls, where the waves will rush round with great force, but for the ordinary face of the sea-wall there is such an ample reserve of stability in the depth of foundation and the great length of the blocks, 14 feet, in the wall, that any special protection for the surface of the rubble is unnecessary.

Note by Colonel Sankey, R.E., Chief Engineer, Govt. of Madras, P. W. Dept., on the above,—dated 11th August 1881.

In G.O., 8th June 1881, No. 1436 W., Mr. Parkes was invited to express his opinion regarding the small section of the Madras Harbour piers as compared with that at Colombo. His reply, dated 4th August, has been forwarded under the despatch from the Secretary of State, No. 26 of the 26th idem.

2. The questions practically raised as put by Mr. Parkes were—

1st.—As to the propriety of the width of the break-water adopted at Madras.

2nd.—As to the necessity for any special protection by large stone on the surface of the rubble base beyond the walls of concrete blocks.

3. Notwithstanding the great wind pressure observable in a severe cyclone at Madras, few who have witnessed the phenomena at such times would be disposed to question the general contention of Mr. Parkes that the height of the seas at such times as measured from summit to trough is very sensibly less than is the case in many other parts of the world, and particularly in places like Wick, exposed to the full swing of the Atlantic rollers.

4. The validity of the "unbonded system" of construction, confirmed as it has been by the effect as stated by Mr. Parkes that heavy seas upon the last built length of the piers "has uniformly served to consolidate them and improve their condition," seems also to be beyond controversy.

5. Still neither of these contentions quite meet the question raised by the Chief Engineer and the Master Attendant, which was that if an acknowledged high authority like Sir John Coode found it necessary to give a thickness of 34 feet to the section of his pier in deep water, it was not clear why the thickness at Madras should have been reduced by 10 feet. Nor are the arguments adduced in support of the narrow section strengthened by the expression of Mr. Parkes' opinion, in paragraph 12, that he sees "no reason for thinking that the break-waters would be strengthened by adding to their width."

6. From paragraph 13 to the end of his letter Mr. Parkes deals with the second question.

7. The Chief Engineer and the Master Attendant, finding at Colombo that large masses of granite were being tipped over the seaward face of the work, so as to form an apron of indestructible material, considered the question of some similar expediency at Madras to be worthy of attention.

8. The outer portions of the rubble base at Madras is composed wholly or in large proportion of laterite, which, if not exposed for long periods to the action of the weather in the form of detached boulders, is held by engineers experienced in its use to be an extremely unreliable material. Though possibly hard on the surface, the interior may be quite soft, and for this reason has long been rejected as a building material, excepting for very minor structures.

9. It being desirable that the behaviour of this material, as applied in the rubble base, should be ascertained, the Superintendent of the Works, Mr. Thorowgood, was requested to state the facts. His observations are as follow :—

"The settlement of the two piers at their ends is at present (8th September 1881) from 1 foot 10 inches to 2 feet 4 inches from the time of setting the blocks till the titan has travelled over them. The greatest total settlement at the south pier has been 4 feet, and this brought the top level 9 inches too low; the greatest at the north pier has been 3 feet 6 inches.

"When the blocks have once made their great settlement there is never any subsequent depression beyond 2 or 3 inches. This is very marked.

"The places of greatest settlement are at 2,500 feet north pier, and at 3,000 and 3,800 feet south pier.

"The height of the rubble bank is now 27 feet before any blocks come on it, so the greatest compression is about one-seventh" (of the total height).

10. In a subsequent note, dated 16th September, Mr. Thorowgood observers in regard to the laterite :—

"It has been one of the greatest difficulties in the construction, because we have had always to allow for the compression as the titan passed over.

"There is, however, absolutely no further settlement after this first and great subsidence. The laterite becomes covered all over with barnacles and shells, and the bases themselves approach a natural concrete in their structure."

11. When further asked for the reasons on which he had based the opinion expressed in the last quoted words, Mr. Thorowgood says in his note dated 3rd October—

"I judge of the state of the base by the result of deep excavations in laterite that has been a long time deposited, and which is very hard to shift."

12. Notwithstanding what has been said in favour of this material, the fact remains that there has been a greater amount of total subsidence in the rubble base than would have been the case with a harder material like gneiss or granite, and this must leave a doubt as to whether such subsidence is not accompanied by the crushing of the material itself, further that the titan in passing over this forms a compacted surface of the crushed material while leaving the interior of the mass to a considerable extent in its original condition.

13. Whether this be a perfectly satisfactory condition for the future of the rubble bases, time alone will show, but whatever the state of the interior, none of the material on either side outside the toe of the concrete blocks is now in any other condition than when first deposited.

14. It is with reference to this part of the work that the suggestion occurred of applying the same kind of protection which has been deemed essential at Colombo.

15. Mr. Parkes, after a clear exposition of the principles to be followed in affording security to walls constructed on bases of loose stone, states as his conclusion that "deep foundations (*i.e.*, sea walls carried down to a sufficient depth below the sea-level—in the case of the Madras work, 24 feet) may be viewed as a substitute for "protection, such as that now being employed at Colombo"—and adds that at Madras "there is such an ample reserve of stability in the depth of foundations, and the great length of the blocks, 14 feet, in the wall, that any special protection for the surface of the rubble is unnecessary."

16. Mr. Parkes is acknowledged to be such a high authority on marine works that the Government may well feel disposed to accept this definite expression of opinion as conclusive, yet it would certainly have been more satisfactory had the reasons assigned for this opinion borne more directly on the facts of the case, and particularly in reference to the comparatively soft quality of the material used for the rubble base.

17. Water, whether salt or fresh, acts on well-ascertained laws, and one of these is that a mass of water in motion when coming in contact with a vertical object, whether it be a bridge pier or sea wall, must find room for escape. The low sea walls as shown by Mr. Parkes, admits of this to a great extent by the simple process of the mass of water in the upper portions of each successive sea passing over the work. But for the lower portion not so vented there is no other escape than down the perpendicular face of the wall till it impinges directly on the foundation; and it entirely depends on the character of the material in the latter whether it is capable of standing the attack.

18. With bridge piers this action is well recognised by engineers and provided against. As showing the effect of a downward scour of this character, the case of one of the great wells for the Sutlej Railway Bridge has been cited. Here the stream attacking this portion of the work, passed, it is said, down the face of the well, scouring the loose foundation out to a depth of some 80 feet, when the well fell forward *up stream.*

19. The question, it will be thus seen, is one of the capacity of the rubble base, composed as it is of laterite, to resist the down scour on occasions of extraordinarily high seas, and is not merely dependent on the depth of the base below the surface of the sea, or again of the manner in which the sea-wall or pier has been constructed.

20. Should Mr. Parkes be perfectly satisfied that, notwithstanding all appearances to the contrary, the conditions have been fulfilled, there is really nothing more to be said on the question.

21. If Mr. Parkes prove right on this point he may justly claim to have executed a work on bolder principles than elsewhere; and, as his work, judged by the length of the piers, will not have cost probably one-half of that of Colombo, foot by foot of length, he will have every reason to be proud of the achievement and to claim as a distinct merit the comparative economy of his great work.

(Sd.) R. H. SANKEY, *Colonel, R.E.*
Chief Engineer, P.W.D.

11th October 1881.

Report by F. N. Thorowgood, Esq., M. Inst. C.E., Superintendent, Madras Harbour Works, on the damage done to the Works by the storm of 12th November 1881,—No. 65 W., dated Madras, 21st November 1881.

I have the honour to submit as detailed a report as I am able of the damage sustained by these works on 12th November. The destruction of the two piers is, however, so very extensive that, even at this date and without having lost any time, my information is somewhat meagre.

Three accompaniments (photographs).

2. *Precautions for bad weather.*—On the afternoon of the 11th November I received a private note from Captain Taylor warning me that the weather was suspicious; but as I have taken all the precautions that were in my power to protect the works and the plant, I could do nothing more when this warning was received.

The two titan cranes were withdrawn as far from the ends of the piers as I considered safe, and my reasons for leaving them where they stood instead of taking them quite back were these :—

I. On two occasions at the north pier, and on one occasion at the south pier, the work has been rather badly damaged nearer shore than where the titans stood on these occasions to which I refer; and I have, from long observation, come to the conclusion that a position a short distance back from the end has hitherto been better than one nearer shore.

II. The position I selected as storm quarters for the titans this season was where the blocks are more deeply founded than anywhere in their rear, and therefore less likely to be undermined. Moreover, the surface of the piers was from 35 to 45 feet wide at these places, and consequently there was a good margin of block work

on each side of each titan (the span of which is 20 feet only); I therefore judged that, as in November 1879 and 1880 these machines had stood well in heavy seas on a narrower pier and shallower foundation, I was not incurring any unwise risk in firmly securing them at the commencement of the pier heads. And in this position they were made fast in every way possible.

3. *Position of the "Hobart" and "Salisbury."*—Similarly with the steamers *Hobart* and *Salisbury*, I had moved them from the south to the north of the harbour, and they were moored by three anchors and a stern fast in absolutely the best berth in the whole harbour during a north-east sea.

4. *The storm.*—The sea rose in the night of the 11th, and by 9 A.M. of the 12th was running very high, and making a clean sweep of the north pier and the Titan at the end. It was also attacking the outer portion from the curve of the south pier with great violence. The wind was not high, nor was there very much white water out to sea, but the waves were very much heavier than any I have seen here before. At times a sea would strike nearly the whole length of the outer portion of the north pier at the same moment, then shoot up in the air and fall in a powerful cascade over the inner row of blocks. This is noteworthy, as will be seen when I describe the nature of the damage.

5. *Force of the waves.*—With regard to the force or height of the waves I have no good record. I have seen much heavier seas in the German Ocean, but I have not seen any equal to it during my five and a quarter years' experience of Madras. I may mention that Mr. R. F. Chisholm, whose judgment in such a matter must be admitted to be very sound, informs me that he considered the seas of 12th November were much higher than those which accompanied the storm of 1872. I think this should be taken much into consideration, as there is a prevailing impression that, because there was not much wind, there could not be a very heavy sea.

6. *Loss of the titan cranes.*—At about 10 A.M. on the 12th the south titan went over into the harbour suddenly, and much of the outer portion of the block work was destroyed. At 12 noon the north titan subsided gently down behind, paused a little, and then was likewise overturned on its side. There it lay for some hours. The north pier was seen to be badly breached also, but the sea was now so very violent that nothing could be made out with certainty.

7. *Loss of the steamers.*—The steamers *Hobart* and *Salisbury* were all this time lying quietly at their moorings, and Mr. Boteler, the Mooring Foreman, who had gone on board in the morning, remained there all day. As the vessels were lying quite steady, and no message was sent ashore from them hinting that they were not holding well, I had no anxiety about them. At about 4 P.M., however, the hawser which answered as a stern fast broke, and almost at the same time the wind got more easterly. Shortly afterwards the fastenings which connected the two vessels gave way, and they parted company and were then in danger of sinking. But now it was found impossible to get a boat or a catamaran out, and the distance (300 yards) was too great for the rocket apparatus to be used, and hence ensued the lamentable loss of life by the foundering of the vessels already reported. Mr. Boteler, who went on board that morning, by a miraculous escape got ashore with a life buoy after being for a long time in the surf. Six of tne crew were also saved by their own endeavours and exertions.

8. *Damage to north pier.*—I will now proceed to describe the damage sustained by the two piers, commencing with the north. The bank of laterite rubble at the commencement of the pier known as the "surf-bank," which was completed in October 1876, is much knocked about by the waves on the north side, and a clean breach through was made just in the rear of the first concrete block, set in December 1876. Measuring from this point, the first 400 feet of pier is hardly affected at all. Beyond this distance the rails and sleepers have been torn off, and there are signs of the centre joint of the blocks having slightly opened for a length of 2,050 from the commencement. From 2,050 to 2,240 the centre joint has opened 5 or 6 inches, the opening being caused by the north row of blocks moving outwards. Never before has this result appeared with work founded at a depth of 19 feet below low water, but we have on other occasions invariably noticed that the result of a heavy sea has been to close the centre joint, even to grinding together of the blocks. On examining the rubble base on the outside of the wall along this part (2,100 to 2,300 about), I find that it has been scoured away for a depth of 5 and 6 feet, slightly undermining the blocks. The surface of the rubble is left now at a depth of 22 feet below low water. It formerly was heaped up well over the bottom course, but now the under-side of that course is exposed. The slope of the base has been flattened, and what is swept from the top has been drawn out over the toe of the slope.

9. At a distance of 2,240 feet the ruin commences. There now follows nearly 100 feet of pier in which the outer or north row of blocks has been swept away, having fallen in the direction of the waves that struck it; the inner or south row of blocks, however, remain stationary up to 2,340 feet. From 2,400 to 2,800, all of which is on the curve, the destruction has been very severe, and for 100 feet in this length the blocks are moved to the very bottom, the blocks in

the lowest course being in some places broken, and the upper blocks have fallen outward in such confusion as to render it difficult to identify them. Some have fallen over the edge of the rubble bank. At places here we find the rubble lowered as much as 7 feet, and the blocks undermined, fallen over, and broken.

10. From 2,800 outward (the curve terminates at 2,937 feet) for 200 feet the bottom blocks remain sound, but are slightly undermined on the north side, the rubble base having been scoured away for a width of 6 feet from the blocks. The upper blocks have here (and from here to the end) been knocked over into the harbour, and have not fallen towards the north.

11. From 3,000 feet to the actual end, 3,870 feet, the lower courses remain in fair order, but a sort of hollow, or ditch, has been scoured in the rubble base in many places at a distance of 3 to 6 feet from the blocks, and in many spots the lowest block is undermined. The action of the waves against the wall has, without doubt, been felt at a depth of 24 feet below low water.

12. At the extreme end, which is founded at a depth of 25 to 26 feet below low water, the
(2·96.) quadrant, or corner block, has stood well, but has settled down 2¾ feet. Also twenty-one rows of blocks at the back of the quadrant remain in fair regularity on the outer side. On the inner, or harbour, side the top courses, and often the second and third courses, have been sent flying into the harbour. The rubble base at the very end was, before the storm, piled up 4 feet above the bottom of the blocks, and it is now scoured out to 4 inches below the blocks in one spot.

13. *The pier head.*—The pier head, by which I mean the last 150 feet of the pier, has stood the sea fairly well, and has failed by sheer force of blows. It is true that only the northern half of it remains, but that remains with much regularity. This is the deepest founded part of the pier, it is the widest section, and on a wider rubble base than the rest. These add to its security. But another reason may be given besides, *viz.*, that Mr. Parkes sanctioned the use of a greater quantity of cement per block in this part of the work, and, as a consequence, the blocks have not broken so much as in the other portions of the ruined wall.

14. The ruin of blocks along the inner, or harbour, wall of the pier has prevented my getting many observations of the bottom, but where Mr. Beardmore has sounded at present it seems that the rubble base has not been disturbed. This is clearly the case at the place where the north row of blocks have fallen over northward.

15. *North titan.*—The titan crane went completely over during the 12th November, and is now buried by the blocks of the pier head. It is useless to speculate on how it came to fall, but I fancy that first the hind wheels gave way and it then capsized, afterwards to tumble over in the general ruin.

16. *South pier damage.*—There remains a greater length of the south pier intact than of the north, which no doubt is due to the protection given by the latter. The wall stands quite secure to 2,550 feet from the commencement, and there has been no opening of the centre joint, as at the north pier. Up to nearly 2,809 from 2,550 there remains the inner, or north, row of blocks standing secure, but the outer row has been knocked over outwards. There then follows a gap of about 200 feet where the blocks have fallen southward in such confusion that at present I cannot say what has occurred, nor whether the bottom blocks remain in position.

17. Following the foundation outwards we next come to 100 feet, where there appears to be no variation in the lower blocks, which are the same as when set. But from this point (3,100) outward there is much undermining of the rubble on the outer wall, the depth of scour being in some places as much as 3 feet below the bottom of the lowest block. Throughout the remainder of the pier where damage has occurred the blocks have fallen inwards. From 3,100 to 3,140 there is much scour and undermining of rubble, whereas from 3,140 to 3,200 the rubble is heaped up against the blocks. There does not appear to be any place where the bottom blocks have actually disappeared, but the amount of sinking is most remarkable.

18. *South pier head.*—The actual end of the south pier has suffered severely, although founded at a depth of 26 feet below low water. The lower blocks alone remain, and these are undermined by the eddy round the end. The upper blocks at this place have fallen over in hopeless confusion, and the whole seems to have sunk very much.

19. But the wreck of the south pier is not so great as of the north, even in the outer portion, except at the very end, as there remain three sections, or islands, in the whole damaged length of 1,400 feet, the aggregate length of which is 210 feet. Whether this is in any way due to the fact that the base is chiefly found of the Pallavaram stone instead of laterite, I will not venture an opinion, but this difference between the two piers does exist. The first of these islands is 40 feet long and is at the end of the curve, at a distance of 3,020 feet from the commencement, where the bottom seems to have been undisturbed. Then, again, at 3,370 feet there remains a portion of the pier fairly complete for 50 feet, but greatly sunk down. Here there is no undermining of the base. Again, at 3,720 feet from the commencement there is a length of about 100 feet of the pier which is hardly damaged at all, but sunk

down to almost high-water level. The rubble base at this point has not been scoured away from the bottom blocks. From this point to the end at 3,950 feet there has been very great settlement, but at present I cannot accurately give the amount. It appears to be quite 3 feet 6 inches. Levels will be taken when practicable.

20. *South pier titan.*—The south titan crane has fallen over into the harbour where it stood, and is not so much buried with blocks as the north crane. It is quite possible that this machine may be recovered.

21. *Damage to coast, north.*—The devastation caused by the sea of the 12th along the coast to the north is very great, but the harm done is almost entirely the result of actual wave blows, not of erosive action. The railway that we had constructed to carry material to the protective works is almost entirely destroyed, but the materials will be saved. The revetment along the road by Mr. Coleman's house is much flattened down, and the walls of compounds beyond are broken down by the waves washing over.

22. The sea encroached badly opposite the Biden Sailors' Home and all along that portion of the coast.

23. Further to the north the damage was not so serious. I have had many applications for repairing the walls which the sea has demolished, and I suppose I ought to repair them again, as I did so in 1879. But it is pretty certain that, if there had been no harbour at all such waves as we had on the 12th would have done much damage.

24. *Buoys.*—Among other damage done in this storm there were six of the new buoys carried away. It is hardly necessary to say that they did not drag their moorings, but in every case some part of their chain gave way. The large buoy that was moored to four screws was one of the first to come ashore, and it is clear that the shackle of the chain failed in this case. My divers have not succeeded in getting the chain up yet, as it buried itself in the sand, when it fell. Four of the other buoys failed by the shackle giving way, and the sixth buoy failed by the mooring ring breaking.

25. The chains and shackles of these buoys are of first-rate workmanship and material, but there is no doubt that the pins of the shackles worked free, although secured in their places by a small turned pin of steel. This is generally split at one end to prevent its working out, but in these moorings there is no such split. The cables of all the buoys were rather taut, but it was absolutely necessary to have them so taut that the swivels were clear of the ground at low water. The buoy to which the two steamers were moored came ashore in the evening of the 12th.

26. *Message to Mr. Parkes.*—I telegraphed to Mr. Parkes on the 12th as follows:—"Heavy sea. Both titans gone. Much damage to piers." And again on the 14th I telegraphed more details and of the sad loss of the steamers and crew. I received on the 18th the following message from Mr. Parkes:—"Passage taken 9th December. Wire, when known, state of remaining courses in damaged parts." And to this I have replied as concisely as I could.

27. More will be known when all our levels and sections have been plotted, but at present I have given all the information I have been able to get by means of divers and soundings. It is perhaps rather general, but I trust that it will serve to show the degree and nature of the damage done. In the meantime greater details are being obtained every day by Mr. Beardmore, who is constantly afloat.

28. There are some protective works that might be done to the remaining portion of the north pier, but I really hesitate to do anything until Mr. Parkes has seen the work as it was on 13th November.

29. I forward some photographs of the damaged work with their descriptions written on the back. They form a painful contrast to the photograph I recently had the honour of submitting, taken on 8th October.

Report by G. L. Molesworth, Esq., Consulting Engineer to the Government of India for State Railways, on the Madras Harbour Works after the Cyclone of 1881,—dated Calcutta, 1st March 1882.

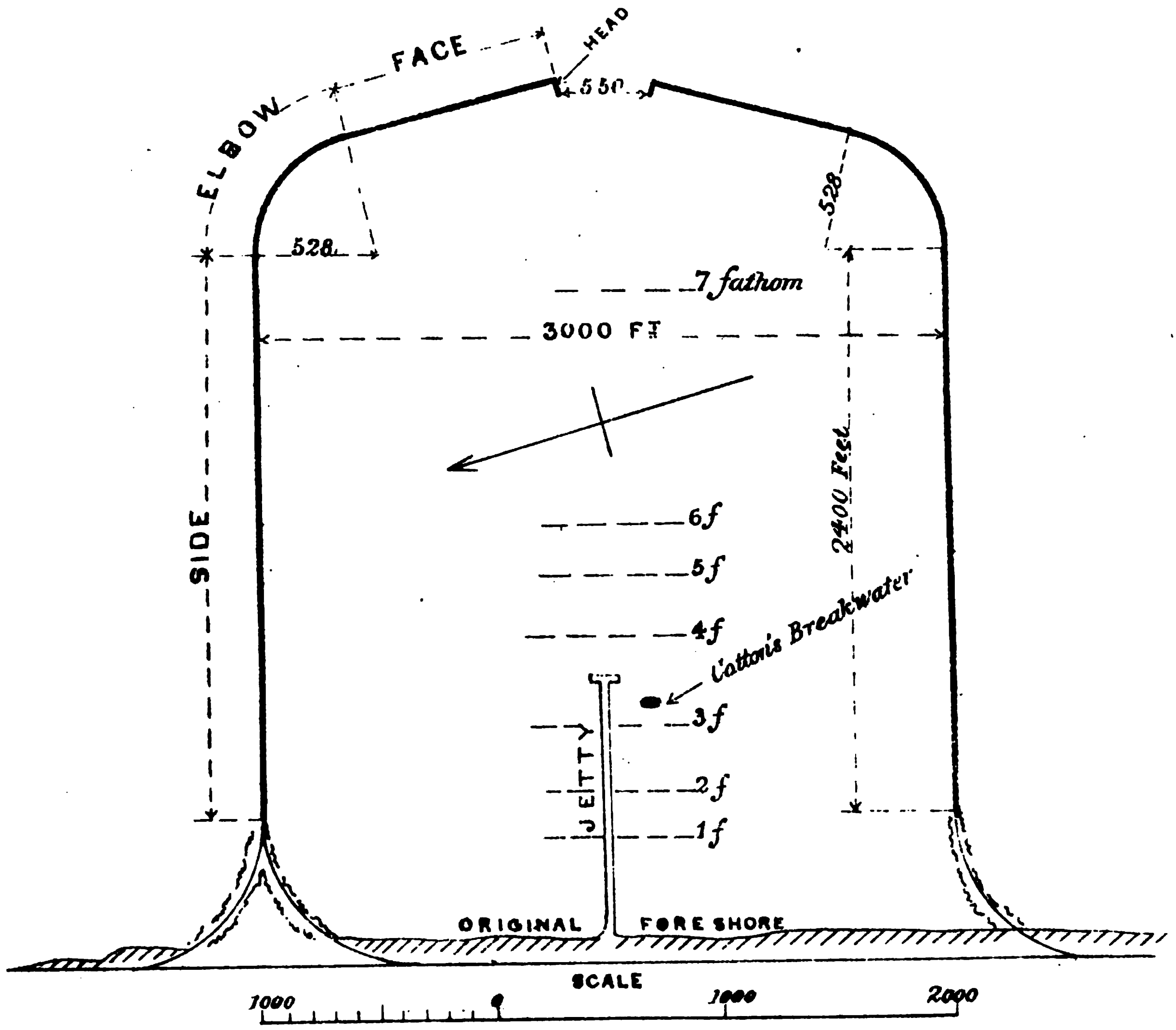
Madras Harbour.

I have the honour to report that, in compliance with the instructions contained in your letter No. 71, dated 8th February 1882, I proceeded to Madras with Lieutenant Stiffe of the Royal Indian Marine, and, in conjunction with that Officer, made a thorough investigation of the harbour works there, and collected such evidence as was necessary to enable me to arrive at definite conclusions on the points which you have referred to me for my opinion.

2. Throughout this investigation, although I have discussed every point of detail with Lieutenant Stiffe, and derived from his technical knowledge and experience much valuable information and useful suggestions, and although I believe that our views have coincided in all questions of importance, yet I have thought it desirable that we should each submit to you separate and independent reports, an arrangement which will allow us respectively to lay our views before the Government more freely and decidedly than would be possible were our reports combined.

MADRAS HARBOUR *DIAGRAM No. 1.*

BLOCK PLAN



ceased, and the work of laying blocks was carried on without further interruption. The south pier, 3,970 feet long, was built between the 19th of November 1877 and 31st October 1881, or in 1,442 days, giving a rate of progress averaging 2·75 feet lineal of pier per day for one pier; the north pier was progressing simultaneously.

separate and independent reports, an arrangement which will allow us respectively to lay our views before the Government more freely and decidedly than would be possible were our reports combined.

3. I arrived in Madras on the 15th of February, and having reported my arrival, I received every assistance possible from His Excellency the Governor, from Colonel Sankey, the Secretary, from Captain Taylor, the Port Officer, and from Mr. Parkes, who kindly placed at my disposal all the information he possessed and rendered me valuable aid in my investigations.

4. My first aim was to ascertain generally the position of the fallen blocks, and this I have been able to do from the careful cross sections which have been prepared by Mr. Beardmore, and from the notes of Mr. Underdown, an extremely intelligent and experienced diver, supplemented by personal observations which I have made myself, both by means of the sounding lead and the diving dress.

5. Before I record the results of my investigation, it will be desirable to describe briefly the character of the harbour and harbour works, and the storm that has so severely damaged them.

6. Madras formerly had a perfectly open roadstead with a sandy beach, in which the depth of water increases rapidly close to the shore, but more gradually as the distance from the shore increases.

7. At 1,000 feet the depth is 4 fathoms, at 2,000 it is 6, at 3,600 it is 8, and, at 6,000, 9 fathoms, thus only shoaling 1 fathom in a distance of 2,400 feet outside the harbour.

8. The currents appear to be strongest from the south-west from May to July, and from the north-east from November to December; they are evidently light, but no systematic or authentic experiments appear to have been made to determine their intensity.

9. Captain Taylor, the Port Officer, estimates the average strength of the current at 2 miles per hour, and the maximum reported is 3 miles per hour. Mr. Parkes states that he made only such experiments on the strength of the currents as enabled him to form the opinion that their intensity was too slight to affect the works in any way. The south-west monsoon has a tendency to produce ground swell, while the north-east monsoon produces chopping seas.

10. The range of the tide between high and low water varies from 2 to 3 feet.

11. From all the information I can obtain, it would appear that the waves produced by either of the ordinary monsoons are not of sufficient magnitude to be dangerous or destructive to the harbour works, but those generated by the cyclonic action are alone to be dreaded.

12. Taking the periods and position of 20 severe cyclones that have occurred in these seas between 1787 and 1878, I find that—

1	occurred in March.
8	„ „ May.
3	„ „ October.
6	„ „ November.
2	„ „ December.
20	

Of these, 9 were to the north, 8 to the south, 3 at Madras.

13. The formation of a detached break-water was proposed several years ago, and, on the recommendation of Captain (afterwards Sir Arthur) Cotton, some loose stone was deposited in this year 1835, and allowed to form its own slope as acted upon by the waves. It appears, however, this work did not advance beyond the experimental stage, for in May 1839 the Master Attendant of Madras reported that the length of the work from N.N.E. to S.S.W. was found to be about 76 feet, and the extreme breadth from E.S.E. to W.N.W. was about 55 feet, the soundings varying from 12 to 25 feet. He also reported, "The stones do not appear to have been moved by the action of the sea from where they were originally placed." The remains of this experiment are still extant, near to, but slightly closer to shore than, the jetty head. I have marked the position of these stones in Diagram No. 1.

14. The screw pile jetty was constructed many years before the commencement of the present harbour works, which were commenced in December 1876 under the supervision, and on the designs, of Mr. Parkes.

15. The general plan of these works is indicated in Diagram No. 1. The north pier was commenced on the 17th of December 1876, and the south pier on the 19th of November 1877. The construction of the north pier in advance of the south pier caused a large accumulation of sand in the proposed harbour, but as soon as the south pier was run out into a sufficient depth of water, the accumulation of sand in the harbour ceased and was transferred to the outside of the harbour in the angle formed by the south pier with the shore.

16. Considerable difficulty was experienced in laying the blocks owing to the accumulation of sand in shoal water; but so soon as the pier ran into 4 fathoms of water, all difficulty ceased, and the work of laying blocks was carried on without further interruption. The south pier, 3,970 feet long, was built between the 19th of November 1877 and 31st October 1881, or in 1,442 days, giving a rate of progress averaging 2·75 feet lineal of pier per day for one pier; the north pier was progressing simultaneously.

17. The finished cross section of the pier in deep water is shown in Diagram No. 2.

18. The height of the rubble base varies with the depth of water, being about 25 feet at its deepest part; the width of the rubble base is 78 feet at the top with slopes of 1 to 1.

19. The size of the stones of which the rubble base is composed, varies from 5lbs to 2 cwt.

20. The rubble was deposited *in situ* from steam hopper barges, and its surface levelled by divers to receive the blocks.

21. The rubble base is composed partly of quartzose gneiss and partly of laterite. The side of the south pier is chiefly formed of stone, whilst that of the north side of exceedingly good laterite. Unfortunately the quarry from which this laterite was obtained was exhausted, and the laterite obtained from the new quarry is by no means equal to that obtained from the original quarry. The elbows and faces of both piers are formed principally of laterite from the new quarry, but supplemented occasionally with a variable admixture of quartzose gneiss.

22. The specific gravity of the quartzose gneiss is 2·7, which, after allowing for interstices, would give a weight of 6¼ tons per 100 cubic feet of rubble in position.

23. The specific gravity of the laterite is about 2·4, that of the sand on which the rubble base rested is 2·1, whilst the specific gravity of the concrete block is about 2·3.

24. I had several of the blocks of granite and laterite broken by the sledge hammer.

25. The laterite from the original quarry, though softer, was more tough than the gneiss, and it usually required two, and sometimes more, blows to break a small block, whilst a single blow sufficed to break a gneiss block of the same size.

26. An Eurasian overseer was stationed at the quarry to check the character of the laterite sent on to the works, but notwithstanding the fact that a considerable quantity was rejected, there is no doubt that laterite not equal to that obtained from the original quarry has been used in the work. The settlement of the work over the rubble base has varied. Over the gneiss the settlement was extremely small, and in some instances no allowance was made for settlement when pitching the blocks. The average settlement of work over laterite obtained from the original quarry was about 18 inches, whilst that on the laterite procured from the new quarry averaged about 3 feet, and in one case was about 4 feet.

27. The blocks were laid in position by a titan, or large travelling crane with overhanging arm, and the principal settlement took place when, or soon after, the weight of the titan was brought on to the blocks.

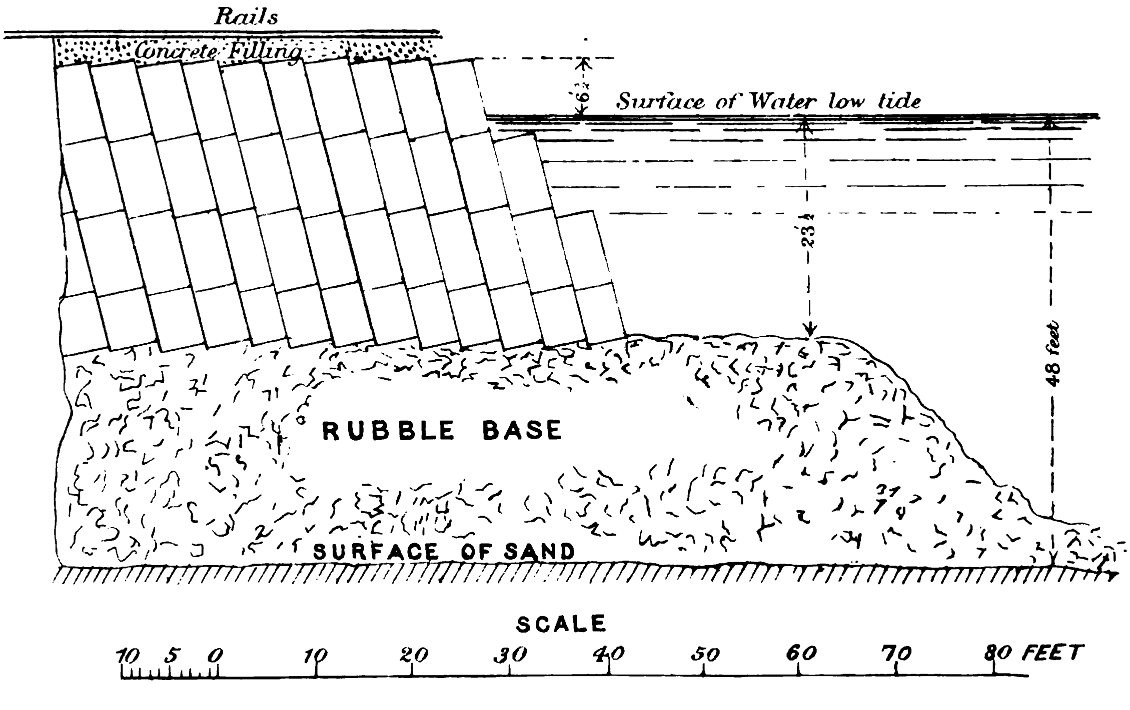
28. The settlement did not, as a rule, leave the blocks more than 6 inches below the level designed for which the blocks were pitched, and in most cases the settlement was less than 6 inches.

29. The blocks were set to a batter of 3 inches to the foot, as shown in Diagram No. 3.

MADRAS HARBOUR

LONGITUDINAL ELEVATION

Batter of Courses 3 inches per foot



30. Throughout the work there is no bond whatever, the blocks merely resting on each other and forming two separate parallel walls in contact with one another, but each block has a tenon on its upper surface, and a corresponding mortise on its lower surface to prevent one block from sliding on another.

31. The blocks are summered on the elbows to allow for the additional length on the outside of the curve.

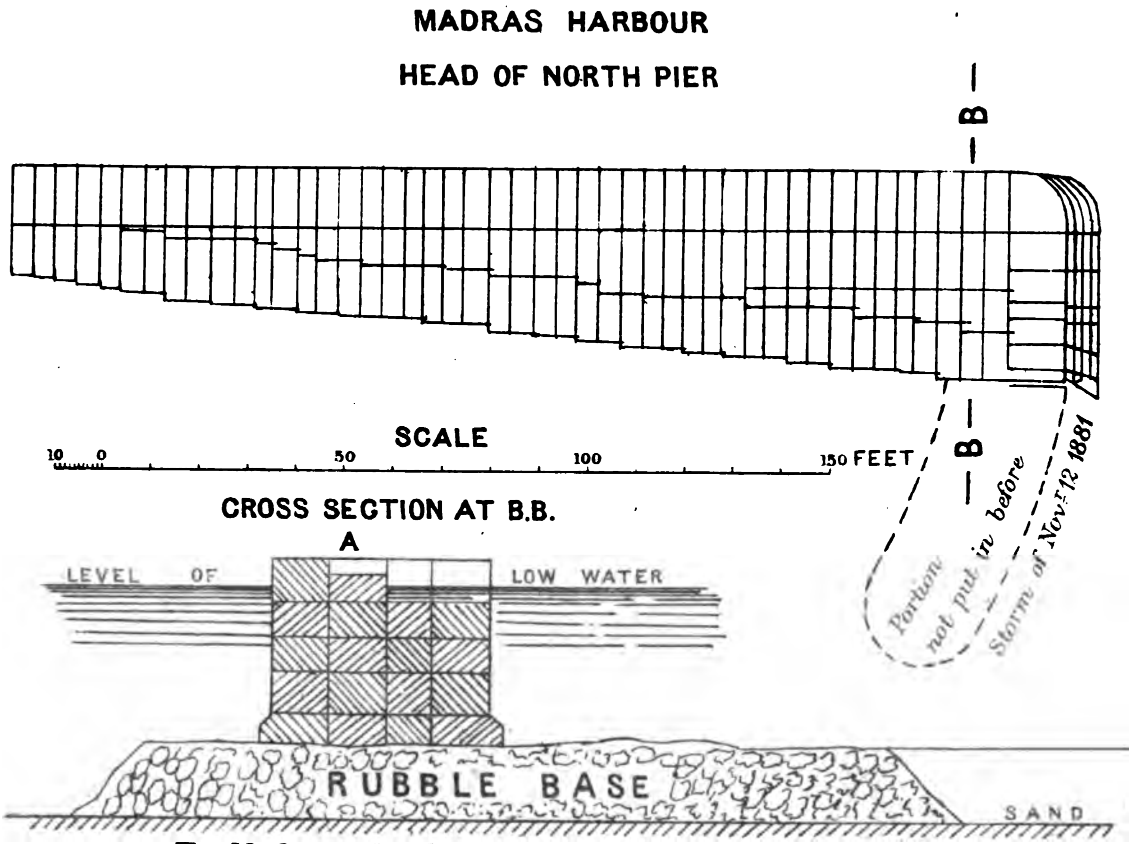
32. The inequalities of the top are filled in with concrete in cement so as to form a level bed for laying sleepers and rails on the pier.

33. The concrete of which the blocks are formed is of excellent character, but the blocks were sometimes used too soon, in some cases having been deposited in site one month after manufacture in the lower courses, and two months after manufacture in the upper course, though, generally, the blocks were used two and three months after manufacture in the lower and upper courses, respectively.

34. The settlement which I have above described naturally caused fracture in many of the freshly-made blocks.

35. The greatest depth of water in which the piers have been founded is 8 fathoms.

36. The pier heads are widened out, as shown in the accompanying Sketch Diagram No. 4.



The blocks not hatched have been displaced in the storm of the 12th Nov. 1881 The block A was lying flat

But the dotted portion had not been executed when the storm of the 12th of November 1881 damaged the harbour works. The blocks were gradually stepped down from the point where the widening took place, so that the bottom of the blocks at the head is about 31½ feet below low water level.

37. The total length of the piers is—

	Feet.
South	3,970
North	3,866
Total	7,836

from the beginning of the block work.

13,643 blocks have been used in the works. The ordinary blocks are 12′ × 8′ × 4½′, measuring 16 cubic yards and weighing 27 tons.

The foundation blocks are 14′ × 6′ × 4½′.

38. In round numbers the composition of a block is—

1 of cement.
2 of sand.
5 of broken stone.
2½ of large stone.

39. The cost of the rubble delivered at the harbour was R1·58 per ton, to which has to be added R·37 for depositing from barges, making a total cost of R1·95 per ton of rubble base, and this, after allowing for interstics, would equal about R12·2 per 100 cubic feet. The cost of cement varied from R40 to 45 per ton. The cost of a block 12′ × 8½ × 4½′, or 16 cubic yards, and weighing 27 tons, averaged about—

	R	A.	P.	
	142	4	0	for manufacture.
	30	4	0	for setting.
or a total of .	172	8	0	*in situ.*

40. The total cost of the work in round numbers, after allowing for the materials in hand, is as follows :—

	Lakhs of rupees.
Preliminary expenses	3¾
Piers	41
Plant	5¾
Contingencies	2¼
Establishment	3½
Total	56½

or an average of R720 per lineal foot.

41. The progress of the work from the commencement to the end was without drawback, if we except some difficulty experienced from the accumulation of sand which prevented the laying of blocks at a short distance from shore, and subsequently caused uneven settlement at that point, and the work was rapidly approaching completion, as but little remained to be done beyond the return walls at the pier heads in order to complete the design. Had the work stood, it would have been the cheapest and most rapidly constructed break-water on record; but on the 11th of November 1881 there were indications of an approaching cyclone, and the titans were made fast on the pier heads where the mass of blocks was of greatest width.

42. The cyclone has been described by Mr. Pogson, the Government Astronomer, as "having exhausted its greatest force while crossing the Bay before reaching the coast of Southern India, which would account for the high destructive sea far beyond what might have been expected from the meteorological indications accompanying its progress. The centre of the storm must have struck the coast considerably southward of Madras * * * * The veering of the wind was as usual for cyclones southward of Madras.

43. The result of this cyclone was the wreck of the faces and elbows of the north and south piers, the wreck being more complete at the elbows than on the faces, whilst the sides remained practically uninjured.

44. Some astonishment has been expressed at the failure of the break-water under the influence of a cyclone that has been apparently insignificant in intensity; but this idea has arisen from an imperfect comprehension of those influences which are most destructive to a work of this character. Surface waves are not the worst enemies against which harbour works have to contend. The wave of translation, the heavy ground swell, generated at a distance from shore, is a far more formidable agent of destruction. This wave has been estimated to be eight times as powerful as a surface wave, or wave of oscillation, and I do not hesitate to say that a very severe cyclone, having its origin near Madras and passing over it, would not produce so severe an effect as a lighter cyclone originating at a great distance and travelling in the general direction of Madras.

45. The actual presence of a cyclone, whilst creating great disturbance in surface waves of pyramidal form, would rather tend to check the ground swell in its immediate vicinity. Scott Russell, who has devoted much attention to the study of waves, thus describes the wave of translation:

"These rollers or ground swell did not merely oscillate up and down and backwards and forwards, and they could not be checked or turned back by giving the wall a particular curve suited to the form of cycloidal oscillation. These great waves of translation constituted a vast mass of solid water moving in one direction with great velocity, and this action was nearly as powerful at a great depth as at the surface. A roller, 20 feet high, would produce a pressure of about 1 ton per foot."

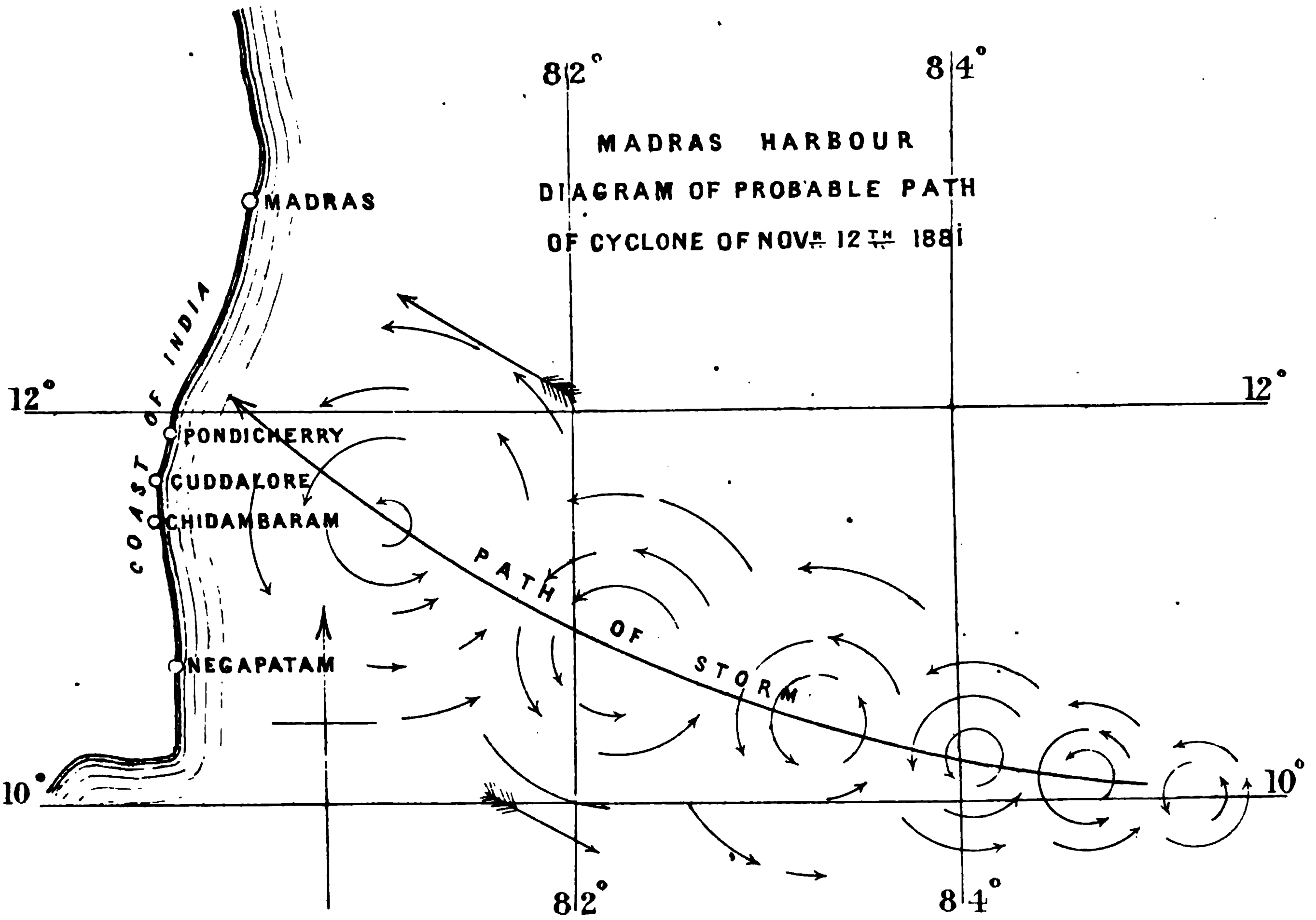
46. The cyclone in question was south of Madras, but north of Negapatam, and its southerly position would necessarily make it the more formidable in its action on harbour works at Madras. I have endeavoured to fix the exact path of the storm by Beaufort's rule, but the winds on shore were evidently so variable and abnormal as to prevent the determination even of an approximation to its path.*

47. We can, therefore, only assume the probabilities in this case from the general laws of cyclones, which, Beaufort states, commence to the east in the Northern Hemisphere, and travel

* See postscript, with Mr. Eliot's particulars of the cyclone.

along a path, not exactly west, but inclining a point or two towards the north, and as they advance, they seem to be more inclined to curve away from the Equator.

48. Occasionally they are found to cross the line of shore and to sweep over the land, but by far the greater number seem to be repelled by the coast, and to be deflected back north-east or to break up. This would indicate a path roughly indicated in Diagram No. 5.



49. Reid in his "Law of Storms" is of opinion that the heaviest swell proceeding from a storm may be that which is propelled forward in the track in which the storm is following as the undulations in this case would be constantly receiving renewed impulses from the storm in its progression, and that the great undulations raised are along the radii of the whirlwind circle, and roll straight onward in the direction of the tangents to the circle. It will be seen on examination of the direction of the arrows in Diagram No. 5, that a storm to the southward of Madras would tend to heap up the ground swell, whilst one to the northward would to a certain extent neutralize it, and that such a course as the cyclone of the 12th of November might reasonably be expected to take is the most trying that could be taken as regards the harbour works of Madras. Whether this cyclone was unusually violent or no, it is of course impossible tos ay, as it had at most exhausted its violence when it reached the coast. The action of the wind blowing off shore would naturally tend to shorten the swell, to convert length into height, and to make the blow delivered by the waves more rapid and violent.

50. Mr. Chisholm, whose past experience in harbour engineering qualifies him to express an opinion, has graphically described to me the action of the waves, both on this occasion and also in the cyclone of 1872. On both these occasions he had an opportunity of carefully examining the waves, and he has expressed a decided conviction that the waves in the storm of November 12th, 1881, were far more formidable than those of the cyclone which passed over Madras in 1872.

51. I have dwelt at some length on this point, in order to combat the popular idea that the storm which wrecked the Madras harbour works was altogether insignificant in its character.

52. The accompanying Diagram No. 6 roughly indicates the general state of the work.

53. The black portions are those which still show above the level of the water, while the dotted lines show the position of the blocks under water.

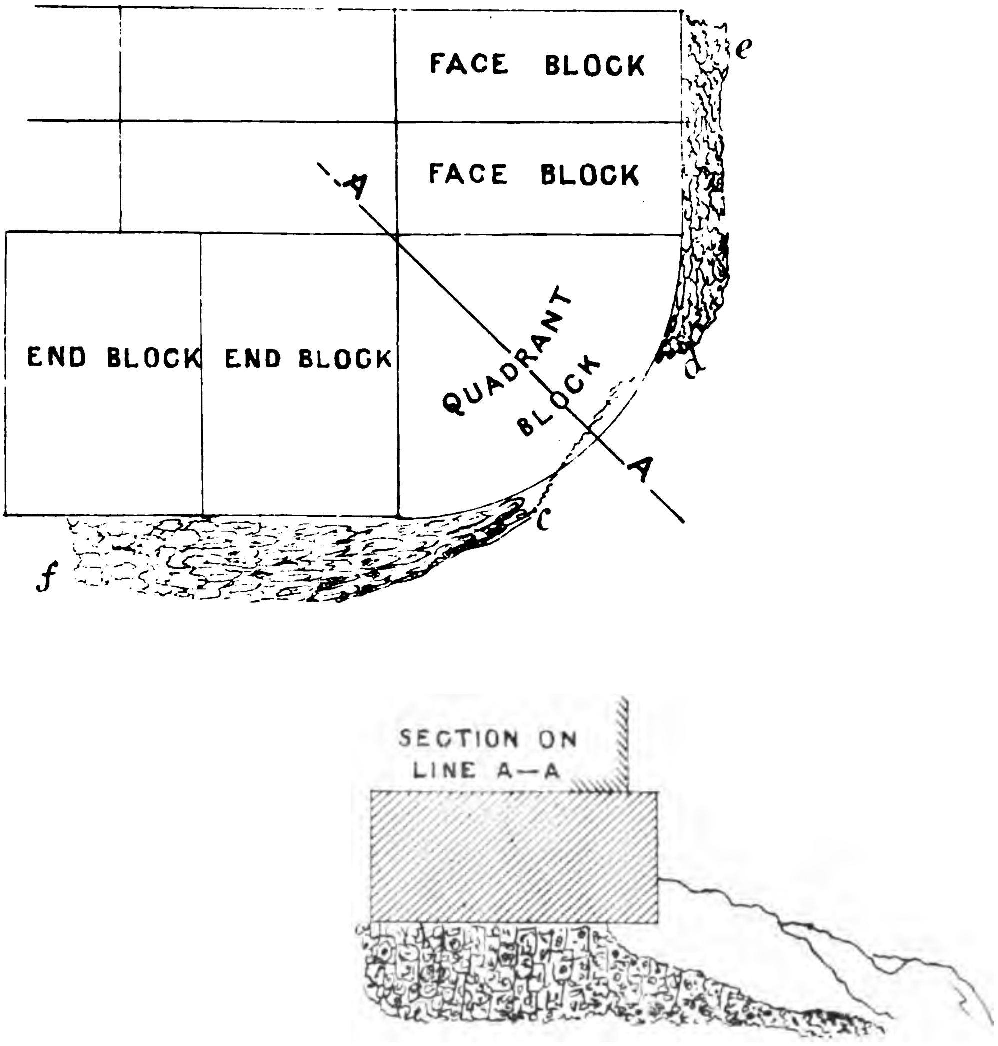
54. The entrance seems to have suffered very little; it has deepened slightly by a foot or two in places, but that appears to have been caused by the current running out of the harbour, due to the large volume of water thrown into the impounded space through the breaches of the piers.

55. The quadrant block at the head of the north pier is for a few feet slightly undermined to a depth of 10 or 12 inches below its bottom, as shown in Diagram No. 7.

MADRAS HARBOUR

DIAGRAM SHEWING SCOUR OF RUBBLE BASE AT HEAD OF THE NORTH PIER

DIAGRAM Nº 7.



56. But the scour only extended horizontally for a few inches under the block, for, while standing upright, I could easily reach with my toe the end of the cavity; on either side of this scour the rubble was piled up against the block 3 or 4 feet above its bottom. The rubble seemed to have been displaced, and I observed no signs of its having disintegrated under the wave action. The lower courses round the head were all there, and apparently undisturbed. The quadrant block on the west of the south pier was underscoured rather more than that of the north pier; but the bottom block also appears to be undisturbed, as in the case of the north pier.

57. No blocks have fallen outwards on the sea-side of the *faces* of the north and south piers, excepting at one place close to the junction of the face with the elbow of the south pier; the bottom blocks and, in most cases, the course above them are in their original position; some may possibly have been driven in slightly, but it is impossible to determine this point with any degree of accuracy for want of some fixed point of departure. The rubble base is in some cases piled up against the bottom block, whilst in others it is underscoured to the extent of 2 or 3 feet; but in no case, except that to which I have referred above, have the *faces* failed from undermining. The failure appears to have been solely due to the displacement of the blocks by repeated blows of the waves. Where the pier has been widened in cross section to three or

four blocks, the addition does not appear to have increased its strength, for the wider portions have suffered equally with those that only consist of two blocks in width. The outside slopes of the rubble base have, for the most part but not invariably, been pulled down to a flatter slope, and the wash of the sand at the toe of the slope has absorbed some of the rubble.

58. The inner slopes of the rubble base appear to have been uninjured by the storm. The left hand section in Diagram No. 8 shows the general type of failure in the *face* wall.

59. The right hand sections show the type of failure in the *elbows*, on which the wave action has been different from that on the *faces*, and the wreck has consequently been more complete. The waves reflected from the face have met the wave directly coming from the sea, and set up a huge confluent wave which closely hugs the elbow and follows round it, tearing up the rubble base and undermining the blocks to such an extent that the outer row of blocks of the *elbows* has, in nearly every case, fallen outwards, whilst the inner row have fallen into the harbour.

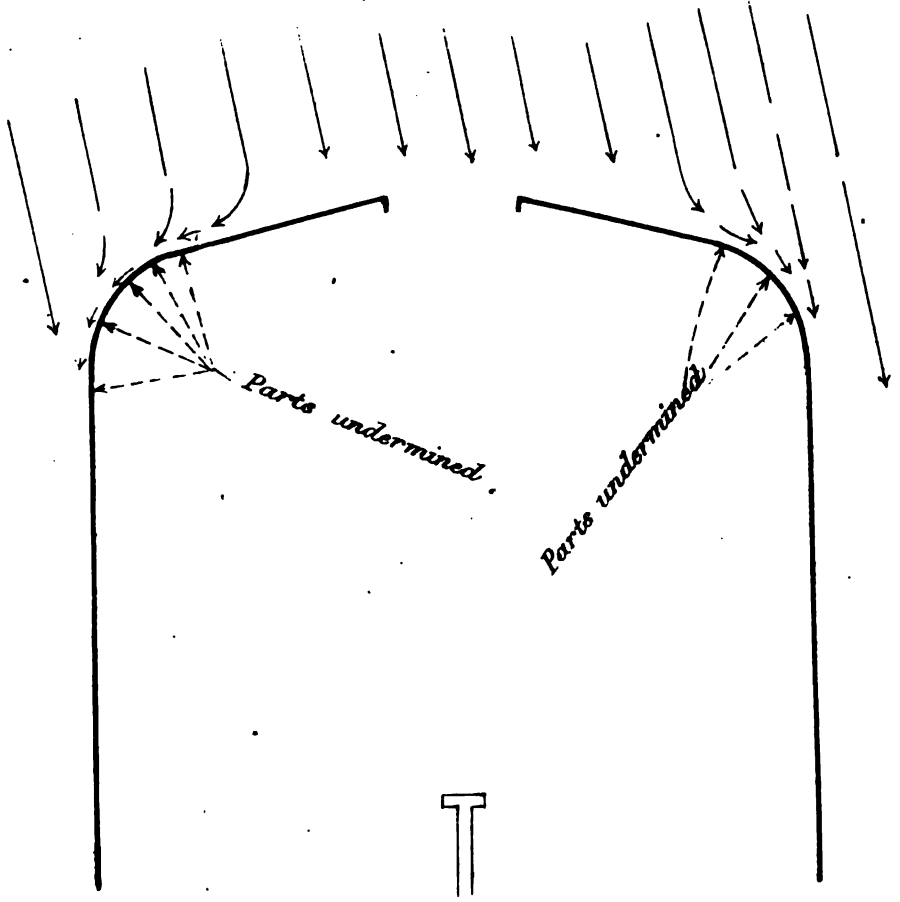
60. The inner slope of rubble face supporting the elbows has apparently been uninjured, as in the case of the base supporting the faces.

61. In some instances, where the blocks were displaced by blows of the wave, they have been prevented from returning to their original position by the projecting tenons of the block below them; this action is illustrated by the central figure in Diagram No. 8.

62. There are several instances of the outer or sea row of blocks standing, while the inner or harbour row has been driven in by the blow of the waves, the rubble base inside the harbour being apparently sound.

63. The confluent action of the waves round the elbows is illustrated by Diagram No. 9.

MADRAS HARBOUR
DIAGRAM SHEWING THE DIRECTION OF WAVES AND THEIR CONFLUENT ACTION AT THE PARTS UNDERMINED



64. At some parts of the pier, which have been uninjured by the cyclone, a constant but slow rocking action of the vertical walls from the action of the swell goes on even in calm weather to the extent of about 1 inch, but the action can only be detected by closely watching the joint; this action is probably severe in storms, for in some instances the joints of the blocks are ground into each other to a depth of some inches. I have observed a similar rocking action on a calm day on the Manora break-water to Kurrachee.

65. I now come to the question of offering such remarks as may be of assistance to the Government in deciding the necessary repairs or modifications to be undertaken to place the work on a more sound basis for the future; but, in order to do so, I must describe the action which the waves have on the existing structure.

66. Hitherto it has been believed that harbour works founded on a rubble base from 12 to 15 feet below the surface of the water would be safe from the action of the waves.

67. Sir John Rennie stated that, in his opinion, waves produced little or no effect at a fathom and a half below the surface. Mr. J. M. Rendel believed that 12 to 15 feet was the level below which the ordinary "*pierres perdues*" were undisturbed.

68. Stevenson, who has had large practical experience in harbours, stated that walls should be founded on rubble at the level of 12 to 15 feet below water, below which he believed the waves to be harmless, and in the instance of Wick break-water, when a mass of masonry weighing 1,300 tons was moved bodily by the waves without breaking up, the rubble base at 18 feet below the surface remained uninjured. Mr. Murray fixed 22 feet as the level below which wave action had no effect on *small* stones, and this experience has been confirmed by many harbour engineers of eminence.

69. Mr. Parkes would therefore appear to have been safe according to the experience of engineers in nearly doubling the depth thought necessary for founding such structures.

70. I have long doubted the innocuous character of waves in deep water. For in the year 1870 I was more than once knocked down and completely rolled over when at a depth of between 40 and 50 feet below the surface, in Galle harbour, on a perfectly calm day, when there was nothing but the usual light but long ground swell, which always rolls in after weeks of perfectly calm weather.

71. It is true that a diving dress renders its wearer very buoyant and consequently wanting in stability of equilibrium, but if any action could take place at such a depth on a perfectly calm day, the effect must be necessarily very severe in a storm.

72. The fact is that scarcely any of the harbours round the English shores are exposed to the action of a heavy ground swell such as I have, when standing on the coasts of Spain and Portugal, seen rolling in from the Atlantic and breaking on the rock-bound shore in calm weather.

73. The "fetch," or space which is necessary to admit of a heavy ground swell getting up, is in general too limited to allow of a heavy wave of translation at those ports which have been selected for harbours.

74. But Mr. Douglas, who has had large experience in lighthouses in exposed positions, where the heavy ground swell rolls in from the Atlantic, states that at Land's End lobster traps at a depth of 30 fathoms are frequently filled with coarse sand and shingle during heavy ground swells, and that, on the Scilly Islands, coarse sand has been thrown, during heavy storms, from a depth of 25 fathoms into the Lantern gallery of the Bishop lighthouse. In the case of the Madras harbour, there is no doubt thst laterite rubble weighing from 5 to 50lbs has been displaced at depths of at least 40 feet.

75. It is probable that any waves that are sufficiently large to injure harbour works will always approach the harbour works broadside on to the shore, no matter what may be the position of the storm, as the known tendency of waves is to lap round towards shoal water as soon as the retarding influence of the bottom is felt. I had an opportunity of testing this tendency some years ago, when it was proposed to construct a break-water at Galle, at right angles to the observed direction of the waves in the harbour and as I had raised a doubt as to whether the direction of the waves on the proposed break-water was the same as that observed in the harbour. To satisfy this doubt I requested the Government to have the position of the proposed break-water buoyed out. When I went with the Master Attendant of Galle to determine the question, though the waves in the harbour were due south, and at the distance of the proposed break-water, it was impossible to discover any change in the direction of the waves, yet on reaching the line of break-water in a boat, the waves were running in south-west or four points away from the direction observed in the harbour.

76. The line of soundings off Madras indicate that the contour runs almost parallel to the shore, but not quite so, and observations on the waves during the storm in question indicate that the waves nearly followed the direction that might naturally be expected from the contour.

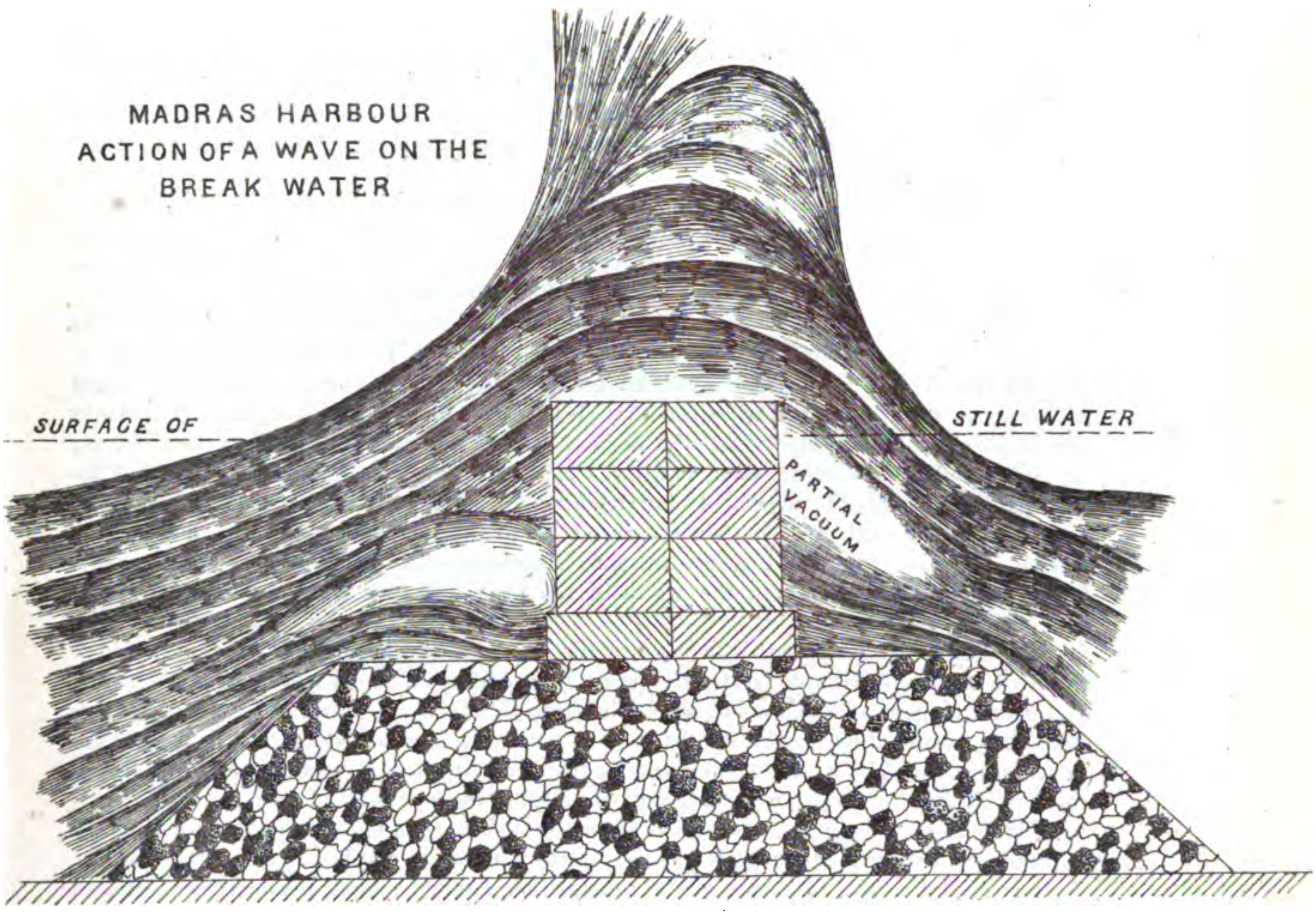
77. I assume then that all waves of magnitude will come in broadside, or nearly so, to the faces of the break-water.

78. I think also that it is doubtful whether we can have a very much more severe test than the storm of the 12th of November. It is, of course, quite possible; but looking at the fact that the condition of the cyclone was most conducive to the production of a heavy ground swell at Madras, and that a limited depth with gradual shoaling (as in the case of the Madras coast) limits the action of the waves, it seems to be very doubtful whether, even if larger waves

were generated, they might not be considerably toned down before they could reach the harbour works.

79. Of course it is impossible to predict what might occur from a "storm wave" such as that which visited Backergunge.

80. The destructive action of the waves on a structure similar to that of the Madras harbour face may be represented in Diagram No. 10, in which we have—



1st.—The direct blow of the wave on the outer block
2nd.—The percussive action communicated by one block to another.
3rd.—The compression of air in the joints.
4th.—The dragging action of the wave on the top block.
5th.—The vacuum formed behind the wall from the receding wave.

81. With regard to the first we have no means of estimating the direct force of the blow Scott Russell estimates that a roller 20 feet high may exert a blow of about 1 ton per square foot, but more than this has been registered by dynamometers with smaller waves, though it is impossible to say whether such an action was local or general.

82. Stevenson has recorded a blow of nearly 3 tons per square foot on the Skerryvore light-house, and 1½ tons on the Bell Rock, but probably the effects of a wave suddenly arrested in deep water would be far more severe than one at Madras checked in gradually shoaling water but in any case the action is severe when the blow is received on a flat surface, as dynamometers fixed on a pile have indicated far less pressure than those fixed on a flat surface.

2nd.—The percussive action communicated by one block to another, or to several other, has been so often illustrated by a series of billiard balls, that it is only necessary to refer to it; and in this case would appear to be denoted when the inner, or harbour, row of blocks has been driven in, although the outer row has stood, and this has happened even when the width has been increased to three or four blocks.

3rd.—The an of the compression of air occurs when the blow of the waves compresse the small quantity of air between the joints, and this concussion communicates to the water also in the joints an action similar to that of the hydraulic ram tending to force the blocks apart; this tendency is increased by the concrete filling on the top of the blocks, which confines the air. I was told

by the Resident Engineer of Plymouth break-water that he has frequently known instances of a block of masonry starting out from the sea-face of a vertical wall after having received the blow of a breaking wave which has compressed the air in the joints behind the block.

That a force thus generated has acted injuriously has, I think, been shown by the fact that in several cases the outer row of blocks has stood after the inner or harbour blocks have been displaced by blows of the waves. In the Kurrachee break-water also, about 80 feet of the seaside wall, consisting of a single row of blocks, was left standing without any support during the remainder of the monsoon, after the blocks on the harbour side had been overthrown.

4th.—The dragging action of the wave on the top of the wall may, however, also have had some share in displacing the harbour side block, whilst the seaside block remained.

The downward motion of the water would possibly increase the coefficient of friction of one block on another, whilst again, on the other hand, the compression of air and the impulse given to the water by such compression might exercise a lifting action which would facilitate the removal of a block.

5th.—The vacuum formed by the receding wave, though less in its action than the preceding forces, must still contribute its share to the work of destruction.

83. The form of break-water which has been adopted by Mr. Parkes is exposed to every action above described. But when the action is not too heavy for it to bear, there is no doubt that this section is the cheapest and most rapid of construction that it is possible to adopt for the *sides* of the break-water, when it will not be exposed either to the broadside action of the waves as at the *face,* or to the confluent action as at the *elbows.* In such a position it would appear to be sufficient, and, if sufficient, then to be the best form for adoption; but when the force is too great for it, as in this case the result has proved, some modification of it is necessary. I do not think that increase in the width of the piers will give corresponding increase of stability.

84. I agree with Mr. Parkes in the view that separate settlement is desirable, and I think that with unequal settlement bond would probably be destroyed, but in re-construction I should prefer an arrangement which would enable the principle of self-adjustment to go even further than that advocated by Mr. Parkes, by re-constructing the faces and elbows on the lines of the existing structure, but with random blocks on the principle adopted with success in many of the French break-waters. A vertical wall is probably the best form of break-water that it is possible to adopt so long as it stands, but when once it begins to fail it will soon be demolished in detail, and the inclined courses render the structure more liable to fail if the portion behind them is carried away. The character of construction I would suggest is roughly indicated in Diagram No. 11.

85. The hatched portions show the probable position of the original blocks in a typical section, whilst the others show the additional blocks it will be necessary to deposit; the addition that should be made to the rubble base is also shown; it is probable that some of these blocks will be displaced, and others will have to be added from time to time to make good any breaches that may arise, but in the event of the displacement of any portion the block that is moved is alone affected, and the stability of the whole is not threatened by failure of a part.

86. Bearing in mind the destructive wave action which I have already described, the random block construction appears to me to possess the following advantages:—

1st.—The direct blow of the wave, instead of being delivered simultaneously on a flat surface, will be delivered in detail on the angular surfaces, and the force will be more broken.

2nd.—The concussive blow will also be more in detail and the blocks better supported.

3rd.—The interstices being large, the air and water will escape more easily, and the compressive action will be lessened.

4th.—Both the drawing action and the vacuum will be less decided.

5th.—The structure would have greater stability as a whole.

6th.—The random blocks, being jammed, one amongst another, will require more force to displace them, and the blocks have to travel over a very irregular surface.

7th.—The displacement of one block will not affect the remainder, and when displaced the block still performs its work of assisting the others.

8th.—If the section be found too weak, it can be strengthened without change of design.

9th.—All the materials of the existing break-water are at hand and available without further expense in moving them.

87. The mode of laying the blocks must be left to detailed consideration after the actual position of the débris of the present break-water has been accurately ascertained. If the verti-

cal wall can be restored by the addition of new blocks, so as to render it available for the distribution of material, it would probably be the most simple and expeditious plan of distributing materials, but, if not, it will be necessary to have recourse to floating shear legs, such as were used at the break-water in Alexandria, as sketched in Diagram No. 12.

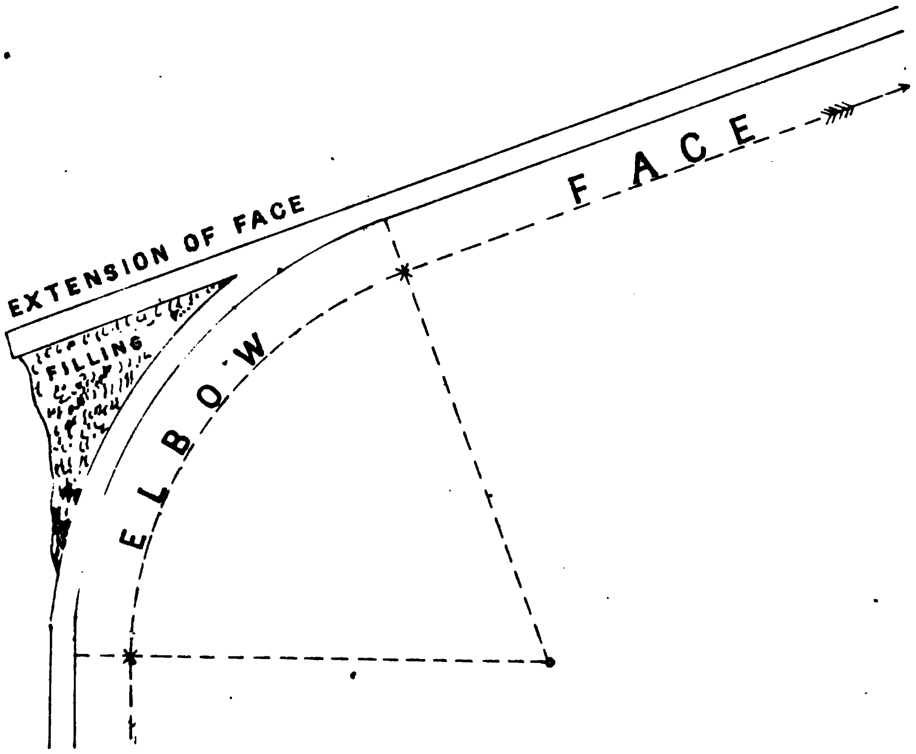
88. Inside the harbour, in comparatively shallow water, a small break-water might be constructed, behind which any hopper barges or floating shear legs might ride in safety during a cyclone. There is no doubt that a break-water re-constructed on the random block system will be far more expensive than one constructed on the vertical wall principle, and when, as in the case of the *sides*, the wall is not exposed to full cyclonic action, I would advise its retention, possibly supplemented by the addition of rubble gneiss thrown down on the outside to protect the lower blocks from underscour. Nor do I think that any harm has so far been done by adopting that form of construction. The blocks have been conveyed to their present position in the cheapest and most expeditious manner possible, and although the materials have been overthrown, they are still in position to assist in the re-construction without further expense beyond that of additions.

89. Recognising the fact that the sides and elbows, as originally designed, are insufficiently strong to resist the waves generated by cyclonic action, and that more strength must be given, the overthrow of the blocks can scarcely be viewed in the light of a disaster, but as distributing the material where it will ultimately be required; though, of course, it would have been better could the original structure have been retained for the purpose of distributing the materials in the most economical and rapid manner.

90. In addition to the re-construction of the faces and elbows on the random block principle, and the protecting of the outer foot of the sides with gneiss rubble, I would recommend the prolongation of the face as shown in Diagram No. 13, in order to neutralize the confluent

MADRAS HARBOUR

DIAGRAM OF PROPOSED EXTENSION OF FACE



action of the waves at the elbows; the space between the elbows and the prolongation of the face being filled in with rubble sloped outwards from the harbour. This prolongation should not, however, be carried far enough to make anything like a re-entering angle for the waves.

91. The width of entrance is so great as to allow a wave of considerable magnitude to enter the harbour. We have questioned the port officer and the pilot on the subject of reducing this width, but both these officers are of opinion that the width should not be less than

500 feet. Looking to the fact that the current across the face of the harbour is small, and that many of the English harbours in which the current is far more intense than at Madras have entrances 300 or 400 feet wide, the width of 500 feet would appear to be unnecessarily large. This question, however, does not press for immediate settlement, as the re-construction should be commenced at the elbows and be carried on continuously towards the entrance, and it would be better to defer the decision on this subject until a series of experiments have been undertaken to determine the intensity of the current, or until further experience has been gained in working vessels in and out of the present entrance. The question of a detached break-water to seaward of, and covering, the entrance has been considered, but is not recommended.

92. It is, of course, very difficult to make an estimate of the cost of reconstruction. The typical section which I have drawn, Diagram No. 11, would give an average of about 4½ additional blocks for each 4½ lineal feet of break-water, or one block per lineal foot; and probably half as much again will be required for settlement of rubble base and displacement of blocks. So that I assume that 1½ blocks, and about 700 feet of rubble base additional will be required per lineal foot reconstructed.

The estimate per foot would be 1½ blocks at R200	= 300
700 feet rubble at 12·2 per 100 cubic feet	= 85·4
Per lineal foot re-constructed	= 385·4 say 400
3,100 feet of re-construction at R400	= 12,40,000
Extension of face and filling	6,00,000
Rubble protection to sides	2,00,000
Additional plant	4,00,000
Contingencies	1,00,000
Establishment	1,60,000
	27,00,000

93. Taking the cost of the work done, after deducting the value of moorings and materials in hand at 56½ lakhs of rupees, and adding to it 27 lakhs for re-construction and strengthening, we have a total cost of 83½ lakhs, or, say, £730,000 for 7,836 feet of break-water, giving a cost of about £93 per foot lineal; and, looking to the cost of other break-waters which have been constructed in water of less depth and exposed to less severe wave action, we shall have still a harbour very cheaply constructed.

94. The following gives the cost of several of the more important break-waters constructed :—

Dover	360 per foot lineal.
Cherbourg	219
Portland	120 (partly by convict labour).
Holyhead	120
Plymouth	300
Marseilles	210
Algiers	122
Colombo (probably)	150

95. The lesson which the Wick break-water has taught on the power of waves in moving bodily a mass of about 1,300 tons renders it impossible to predict the result of the action of waves under certain conditions; but, in view of the fact that the test of the cyclone of the 12th of November 1881 was unusually severe, and that in some parts the outer row of blocks survived this test after losing the support of the inner row, I am of opinion that the break-water, if re-constructed in the manner I propose, will be effective, and, even if partially wrecked, the débris will still be available with the addition of more blocks.

96. In conclusion, I may briefly summarise my opinions as follows :—

1st.—The proximity of a cyclone is no measure of the intensity of wave action.

2nd.—The storm of the 12th of November 1881 was a very severe test, probably almost as severe as any that can occur at Madras.

3rd.—Wave action at Madras extends to depths far lower than experience in English and Continental harbours has led engineers to expect.

4th.—The pier faces have failed almost entirely by the displacement of the 27-ton blocks.

5th.—The elbows have failed, on the sea-side, from underscour of the rubble base, and on the harbour side by displacement of blocks.

6th.—The rubble base has on the sea-side of the face and the elbows been pulled down to a flatter slope, while the rubble base on the harbour side has stood well.

7th.—The sides have from the shore to the elbows been practically uninjured.

8th.—The waves of a dangerous character must always come in broadside on to the shore, or nearly so, whatever the position of the storm.

9th.—The sides of the harbour will not probably be exposed to broadside action of cyclonic waves.

10th.—The entrance has been uninjured by the storm.

11th.—The storm has not increased the accumulation of sand in the harbour.

12th.—The section adopted by Mr. Parkes is the cheapest and most expeditious that could be adopted.

13th.—It is probably sufficient for the sides of the harbour, which will not be exposed to the full action of the cyclonic wave, but the rubble base should be supplemented with gneiss.

14th.—It is insufficient for the faces and elbows.

15th.—The disaster is not serious, as all the materials that have been deposited are available without removal.

16th.—The concrete of which the block is composed is good and sufficient, but in some instances it has been used too soon after manufacture.

17th.—Some of the laterite obtained from the new quarry is unsuitable for the rubble base, and I advise that no laterite be used in reconstruction.

18th.—I am of opinion that the failure of the break-water is not attributable to the character of the concrete or laterite, though in some few parts the catastrophe may have been hastened by broken blocks or unsuitable rubble.

19th.—I would only propose to reconstruct the vertical wall where it can be economically used for the distribution of materials.

20th.—The blocks that have fallen should remain where they are.

21st.—The reconstruction should be on the lines of the present break-water, but on the random block principle.

22nd.—The face should be extended to cover the elbows.

23rd.—The sides should be protected by throwing down additional gneiss rubble on the sea-sides.

24th.—The blocks might be rather larger for the outside slopes, say 30 or 35 tons.

25th.—An inner break-water should be formed for the protection of barges during construction.

26th.—The blocks should not be used within six months from their manufacture, unless they have a greater portion of cement.

27th.—Early action should be taken in the construction of blocks and the quarrying of materials, so as to prevent further demolition of the structure.

28th.—A detached break-water covering the mouth of the harbour is inadmissible.

29th.—The entrance should, if possible, be narrowed, but a decision on this point must be postponed pending further investigation and experience.

30th.—The cost of reconstruction will be about 27 lakhs of rupees.

31st.—The harbour, even with this addition, will, when compared with similar works, have been constructed at a very low rate.

P. S.—Since my report was in type I received and annex hereto the copy of a letter which was sent by Mr. Eliot, the Meteorological Reporter, in reply to a telegram which the Government of Madras sent at my request, to ascertain the particulars of the cyclone of the 12th of November 1881.

1. It will be seen that this letter confirms to a great extent the conclusion at which I had arrived from theory, as to the actual path of the cyclone. I have also had some conversation with Mr. Eliot on the subject, and he thinks it not impossible that the abnormal variations of the wind at Madras to which I have referred, as preventing me from arriving at an approximate determination of the path of the cyclone by Beaufort's rule, might have been due to a small, but separate, local cyclonic action to the north-east of Madras—an action which is not inconsistent with observations he has made in other cyclones; if this were the case, the smaller ground swell from the north-east meeting the heavier ground swell rolling in from the south-east in front of the path of the main cyclone would tend to increase the severity of the wave action.

2. Mr. Eliot has suggested for my consideration whether the failure of the harbour works may not have been due to the waves being isochronous with a pendulous oscillation of the vertical wall rocking on an unstable base; but there is abundant evidence that the failure has not been generally due to the unstable equilibrium of the walls, but to the displacement of the blocks in detail, many of the blocks having been driven in, one by one, and in many cases the lower blocks standing, whilst the upper blocks have been evidently displaced by repeated blows.

March 3rd, 1882. G. L. M.

Report by LIEUTENANT STIFFE, Port Officer of Calcutta, on the Madras Harbour Works after the Cyclone of 1881, dated Calcutta, 13th March 1882.

I have the honour to report my return from Madras, having carried out the instructions conveyed in your No. 72 M. of 8th February; and as Mr. Molesworth is of opinion it would be better I should prepare a separate report, I have the honour to submit the result of my enquiries as follows, premising that, as the actual measurements, general plan, &c., of the present state of the piers will be dealt with by Mr. Molesworth, I do not think it necessary to enter into them in this report.

Plan of harbour.

2. In the first place, with reference to the suitability of the shape of the harbour for the purpose required, the plan appears to me judiciously designed. There is no great choice as to shape, and the only question I have heard raised is as to the position of the entrance. The Master Attendant at Madras is of opinion that the entrance should be about the centre of the north pier in 6 fathoms, instead of in its present position in the centre of the sea-face, but has not, so far as I am aware, put forward the reasons which lead him to prefer this new position, or the objections to the present entrance, beyond stating it to be the opinion of all nautical men that the sea-face must be closed, and that it is a source of weakness to the work. This latter hypothesis does not appear to me at all borne out by Captain Taylor's arguments. The current at Madras is never strong enough to do any harm to a mound of rubble stone, according to the information I received; but I shall return to the subjects of currents.

Mr. T. Stevenson, the eminent Harbour Engineer, lays down as an axiom that the entrance should always be fixed seaward of any other point. All harbours on the English coast that I am acquainted with are so constructed, and notably the great Amsterdam Harbour on the North Sea, a work designed by Sir John Hawkshaw for a similar situation on a straight sandy coast, is similar in shape and position of entrance to the Madras works.

Entrance.

3. The objection that the current sets across the present entrance, which is the only difficulty to ships entering, is common to all harbours similarly situated.

Currents.

4. There are no records of any systematic observations of the direction of the swell or of the currents, and their strengths at different seasons; and I would suggest that a series of observations on these points be at once set on foot, a special observer being employed for a whole year at least to make daily frequent exact observations, especially as the question of the best site for the entrance depends greatly on the first of these points.

Width of entrance.

5. The requisite smoothness inside the harbour may be probably obtained by contracting the entrance, and I believe this may be done without lessening the accessibility of the harbour. The Master Attendant is of opinion that 500 feet is the least admissible width, but, looking to the width of many other harbour entrances,* to the probability that when accustomed to a small entrance it will be found less formidable than anticipated, and also to the fact that from the first without experience, no difficulty has been felt with the present opening of 550 feet, I believe 400 feet will be found a sufficient width; but the exact width should be settled after the observations suggested in paragraph 4 shall have been completed. With such a width I believe no wave of a size to cause inconvenience would exist within the harbours except during heavy cyclones, when I believe heavy swell would roll in through any entrance.

	Feet.
* Portland	360
Sunderland	368
Aberdeen	378

Position of entrance.

6. As regards the position of the entrance, as the decision cannot be acted upon until plant has arrived from England, and the damaged walls have been repaired, there is time to consider carefully whether any alteration shall be made, after making careful observations on the set of the waves and swell through the year. I feel certain that an entrance at the side should not be so near the outer line of surf as the depth of 6 fathoms, proposed by the Master Attendant.

Piers or walls.

7. It is hardly necessary for me to do more than refer briefly to the design of the harbour walls. They consisted, in the normal section, of a base consisting of a rubble mound, 78 feet wide on top, with slopes of 1 to 1, and raised to a height of 22½ feet below low-water line, on which stood two equal walls of concrete blocks, each 12 feet wide, touching each other, but not connected or bonded together. Each wall consisted of a series of columns of four blocks each; each inclined slightly backward at a slope of 3 inches per foot, leaning against the next column behind, and pressed against by the next column in front. The upper blocks in each column were connected by tenons, made on the blocks, to the one next below it; but it was an essential feature of the

design that there was no bond or connection laterally or longitudinally between the various columns. Each block measured 12 feet in depth of bed, 8 feet in height, by 4½ in thickness, excepting the foundation blocks, which were 14 by 6 by 4½, and the normal height of the wall was 29 feet, which was increased by one block in depth near the head for a short distance only. Each block weighed about 27 tons, of which two tons were Portland cement, and they were, at times, set a month after completion. The specific gravity of the concrete was 2·3, so that the weight of a block under water is under 16 tons. The rubble mound was composed of stones of all sizes up to 2 or 3 cwt., deposited out of boats, and the north mound as far as the elbow was of laterite, while the southern one for the same distance is composed of gneiss: from thence to the ends both mounds are chiefly of laterite with a little gneiss mixed.

Comparative cost.

8. The work has been carried out most expeditiously and at an unprecedentedly low cost, being so far only £60 per running foot, as compared with the following:—

	£	
Alderney	100	
Portland	190	lowest estimate.
Dover	360	
Holyhead	160	
Plymouth	300	
Marseilles	210	
Algiers	122	
Cherbourg	219	

The Colombo break-water is said to have cost, so far, about R2,000, or £166 per foot. Even if the completion of the Madras works cost an additional 40 lakhs—an outside estimate—and occupies three years more, this great work will have been constructed at a very low rate and in a very short time.

Section.

9. A comparison shows that the cross section of the original design is slight, compared with most other break-waters, and in its prototype, the Kurrachee work, the vertical walls, which were of the same width, were only three blocks high. Moreover, the sea at Kurrachee strikes the pier at an angle of about 65 degrees with the line of the work, and gives only an oblique blow. The break-water there has not received any damage since the monsoon of 1874.

Description of storm.

10. I would next offer some remarks on the character of the storm. The Master Attendant reports there was no wind to speak of, and that boatmen could have put off outside the harbour; further, that the wind set in at west, and that the cyclonic centre was to north-eastward of Madras, but that it afterwards 're-curved'

It appears, however, from the records of the Meteorological Department, that the centre was southward of east from Madras, and that it reached the coast considerably south of Madras; the wind by the observatory anemometer being at first north-north-west, and only for a short time veering irregularly to north-west, and was never to the west-ward of north-west by west. The direction of the heavy sea at about east by north also clearly proves the centre to have been always to southward of the place. The strength of wind registered by the anémometer was 32 miles an hour, or a moderate gale of wind, as compared with 53 miles in the gale of 1872. The sea was getting up during the night of the 11th November, and the principal damage took place before noon of the 12th, but the greatest barometric depression, showing the nearest approach of the centre, was about 2 P. M., and the wind increased up to about 2 in the morning of the 13th, after which it rapidly decreased.

11. The storm was doubtless very severe out in the Bay, but there is no record at Madras of its having been actually encountered by any vessel. There is every reason to fear that the steamer *Lockyer* from Calcutta foundered in this cyclone. It appears not to have been of large diameter, and evidently decreased in intensity on approaching the coast, but the sea, originating on the advancing north side of the centre of the cyclone, and propelled by it on to the harbour works, was, there is no doubt, very high, and of destructive violence. A very competent observer, Mr. Chisholm, C.E., was of opinion the waves were much higher than in the storm of 1872, or in any cyclone he had seen at Madras. In fact, the waves inside the harbour, which according to that gentleman were much less than those outside, even after the works were breached, reached the platform of the iron pier, and did some slight damage to the planking. This is as high as any sea reported before the harbour was made.

Character of sea.

12. It is to be expected that the waves caused by a cyclone, the body of which passed to the southward, would be more severe than if the centre passed over the place itself. The sea is stated to have come

in with great regularity from a direction a little northward of east, the line of breakers being parallel to the sea face of the north pier; it subsequently shifted slightly to a more southerly direction.

13. *Mars*, the only ship at anchor in the roads, was able to put to sea on the afternoon of the 12th, the wind being then to the westward of north. The P. and O. Co's. steamer *Clyde*, which arrived from the southward the following day, had observed indications of a cyclone to the northward of her, and had showed down to let it pass.

Shipping.

14. I have taken a few soundings, and made careful enquiry as to the depths inside and outside the harbour, and at its mouth, and found the depths somewhat in excess of those shown on the latest Marine survey—possibly owing to a difference of datum. No change has been recorded in the depth of the entrance since the construction of the piers, nor, from the few soundings I took, does there appear to be any deepening or scour acting on the sea bottom outside the entrance by the littoral currents. It appears these are too weak to act on the sandy bottom, and still less would they be able to displace the rubble mound.

Depths; alteration of.

15. It is quite certain that the action of the sea waves or ground swell is felt to a depth far beyond what has been hitherto considered a maximum, namely, 12 to 15 feet, as the rubble base has been acted on both by being spread out into flatter slopes, and also by settling to some extent into the sand, probably by the action of the sea on the sand at the toe of the rubble mound, and by the vibration of the superstructure caused by the blow of the sea. As the top of the rubble base is 22 feet, and at the pier heads 28 feet, below low water, it is clear that the depth at which rubble can be moved by the oscillation of water caused by heavy storm waves must be greatly extended. There is also found a scooping out of the mound just outside the vertical wall which is perhaps caused by the motion of translation of the wave being partly reflected downwards along the face of the wall.

Action of sea at bottom.

16. The so-called break-water of Sir Arthur Cotton was an insignificant affair. According to the records supplied by the Public Works Department, only 2,500 tons of stone were thrown into the sea in about 25 feet of water, forming a small heap of stones 76 feet by 55, rising to a height of 12 feet below the surface of the sea. It lies to southward of, and just inside, the line of the head of the sand pile jetty, and there is now not less than 19 feet over it in any part, but it cannot be said to have disappeared.

Cotton's experiment.

17. For the purpose of describing the present state of the works, I shall refer to the straight portions of the piers extending straight seaward as the 'sides,' the straight parts on each side of the entrance facing the sea as the 'faces', and the curved portions connecting the sides and faces as the 'elbows.' Their condition since the storm is well and correctly detailed by Mr. Thorowgood in his report of 21st November 1882, paragraphs 8 to 19, and may be summarised as follows:

Present state.

Northern pier, total length 3,866 feet, of this 2,240 feet, as far as the commencement of the elbow, are intact, except that for the last 200 feet the longitudinal joint has opened slightly. From the beginning of the elbow to the pier head, a distance of 1,626 feet, the damage is continuous and considerable. Practically the vertical wall has ceased to exist, and has been reduced to a heap of 'random' blocks; the lower or foundation tier remaining generally unmoved. In places the second, or even third, course is standing, but more or less displaced or settled down. It is noteworthy that the pier head, which was widened out to four blocks in width, has equally failed to resist the sea.

Of the southern break-water, total length 3,970 feet, a length of 2,550 feet from the shore, or up to a point a little farther than the beginning of the curve, is uninjured, but the blocks of the remaining 1,420 feet, as far as the end, are little less displaced than in the northern pier.

18. The uninjured parts of both piers stand now at an equal height above the level of the sea, and, as regards the manner in which the fallen blocks lie, it is remarkable that round both elbows the blocks have fallen outwards, as well as inwards, in about equal proportions, while, in the faces or outer straight portions, they have generally been thrown over into the harbour, and the outer blocks have been the least disturbed. This peculiarity has been also found at Kurrachee, on occasions of damage during construction.

19. The rubble mound has not been much affected on the harbour side, but on the sea-side it is drawn out into a long slope, uncovering and in places undermining the foundation blocks, and this action has been most marked at the elbows, where the blocks have fallen outwards. It has also, along the faces, been scooped out into a ditch near the foot of the wall, and has to some extent

settled bodily down, owing probably to the sandy bottom yielding. It has been much washed down also along the still intact sides. At the pier heads, while the northern one is almost unaffected by undermining, except just at the corner for a few inches only, or no further than could be reached by the hand, the south head is reported much undermined, being attacked on two sides.

20. With reference to the causes of the damage to the different parts, the next point to which attention was invited, it appears that on the "faces," where the inner row of blocks is most injured, and has fallen into the harbour, the failure of the wall is principally due to the direct blow of the wave. This blow on the outer blocks has been transferred to the inner row of blocks, and as these were not tied to the outer blocks, they were driven inwards into the harbour. This is illustrated by the familiar experiment of three or more balls suspended, lightly touching each other; when, if one of the outer balls is moved out a short way and then allowed to fall back against the centre one, the blow is transferred to the outer ball on the other side, which will diverge to the same height from which the first ball fell, while the intermediate balls do not move. If this hypothesis be correct, it will account for the northern pier head failing in the same manner as the rest of the wall, although composed of four rows of blocks, part of the outer row only remaining in place.

Causes of damage.

21. The process has, no doubt, been assisted by the following actions which are referred to in many papers on the subject of sea walls:

(*a*)—The hydrostatic pressure of the water due to the difference of level on the two sides of the wall during the passage of a wave.

(*b*)—The action of air between the blocks compressed by the blow of the wave, and tending to force the blocks apart. This action has been intensified by the capping of concrete which has been laid on top of the blocks to form a bed for the permanent-way, and which prevented the egress of the air upwards. The capping has been broken up, even over the parts of the pier which remain standing, in a manner suggesting such action.

(*c*)—The formation of a partial vacuum on the harbour side of the wall.

(*d*)—The dynamic blow of the actual weight of water falling nearly vertically on the top of the wall, chiefly on the inner line of blocks.

22. If we assume that as part of the wave is thrown upwards with great force, so a similar action takes place also downwards, it would account for the hollow or trench scoured out on the sea-side of the wall, and perhaps also for the depth at which the work has been affected.

Downwards action.

23. The failure of the "elbows," where the sea struck at an angle, and was perhaps intensified by interference," appears to be principally due to the undermining of the wall by the lowering of the rubble mound on the sea-side, as here the blocks have chiefly fallen outwards, and the rubble mound has been most severely acted on. The safety of the side walls is, I suggest, due to their meeting the blow end on, and to their being protected to some extent by, the more seaward portion.

Failure of elbows.

24. The fact of laterite having been used for the base has been criticised, and, no doubt, it would have been better had the harder stone been exclusively used. The reasons assigned for its use are the greater facilities for getting a large supply, and the fact that it was expected the rubble mound would not be moved by the sea. In future operations I would use the gneiss exclusively. If, however, the laterite had been one of the principal causes of the fall of the walls, it would naturally be expected the still standing north wall, which stands on laterite, would have settled more than the south wall, which stands on gneiss, but this is not appreciably the case. In fact, the north side wall, considering it was somewhat more exposed, has stood equally well with the south wall.

Quality of rubble base.

25. As regards the waves entering the harbour, Mr. Chisholm is decidedly of opinion they were much less raised than outside the harbour, even after the damage had taken place. The tide gauge shows that the level of the water in the harbour was considerably raised, probably by the water continually poured in by the waves over the piers, so that it ceased to register the height on the scale. The rise amounted possibly to 2 or 3 feet, and gave rise to a current setting out of the harbour mouth of sufficient strength to carry wreckage out to sea. This, no doubt, made the waves in the harbour more hollow and dangerous.

Waves.

As the height of the pier above the ordinary sea-level is 18 feet, this would give the maximum height of wave in the harbour as near 16 feet above sea-level.

Completion of works.

26. I have now to refer to the question of re-construction and completion, and I believe it to be proved that it will be undesirable to attempt to complete the work on the original principle of a vertical wall without any bond—even if it were completed with three walls instead of two for the whole length of the damaged part. The inner row would, I believe, be overthrown nearly as readily as it has been with two rows, and the experience of the north pier head indicates that the same result might follow even with four walls or rows; further, the clearing away of the fallen blocks to make room for the foundations of a vertical wall would be expensive and tedious, and I would adopt the random block, or French system, leaving the whole of the material at present on the ground to form the nucleus of the new work.

Rubble base.

27. It will be necessary, in the first place, to complete the rubble base, and as this will be protected by the superposed random blocks from the action of the sea, I would raise it to a height of 35 feet from the bottom, instead of 22, widening it on top 10 feet on the outside beyond the present dimensions, and allow it to take its natural slope of 1 to 1. If left to itself, this would spread out into a long slope of 8 or 9 to 1; but if the large blocks are deposited on it at once, it will probably remain at about 1½ to 1 after settlement. The toe of the rubble mound on the sea-side should be protected by an apron of rubble extending 30 feet outside the mound and 2 to 3 feet thick.

Material.

28. I would use gneiss stone exclusively for the mound, and it should be, as far as possible, selected as to size at the quarries on the French system, the smaller stone being used in the centre of the mound and the larger for the outside. It can all be tipped from boats.

Random blocks.

29. The new blocks should be deposited close together, and as soon as possible after the mound has been completed to its full section, and they should extend to a depth of 25 feet below the sea-level. If piled up to a height of 6 feet above high water, they would gradually settle down, and would for some time require fresh blocks to be added to fill up the section. They might be taken out on barges and deposited by a floating crane, such as those used at Port Said, Alexandria, &c.

Protective blocks.

30. I would also deposit a row of blocks along the outer toe of the still standing side walls for their whole length as they stand, after completing the rubble mound, where it has been washed down to its former section.

Size of blocks.

31. There is a convenience in adhering to the dimensions of the present blocks, owing to the formation of the block ground and travellers, which gives great facilities for making, storing, and transporting the present pattern of block, but it might be considered whether the thickness should not be increased 1 foot, even if the breadth were diminished, so as to lessen the chance of fracture of blocks after being placed *in situ*, and I would not set any blocks in less time than four months after completion, to give them time to thoroughly harden, especially as, in the style of work proposed, they are subjected to more severe transverse strains than in a regular wall.

Resumption of work.

32. Whatever plan of re-construction be decided on, no time should be lost in resuming the tipping of granite rubble on the outside of the piers still standing to complete the section and secure the "sides" from chance of injury, and also the manufacture of block to the full extent of the storage capacity of the block grounds, which will be useful in any case.

Cost.

33. I have made a rough estimate of the cost as follows:—

	Lakhs.
Plant	4
Protective blocks along side walls (1,250)	2½
Rubble mound completion, 450,000 tons at R 2	9
Random blocks, at 7 blocks per yard forward	14
Establishment and contingencies	2½
Total	32
Deduct blocks on hand and value of plant after completion	2
Net Total	30

and I think this would not be exceeded, but it would require more detailed calculations to arrive at any very exact result.

Detached break-water.

34. It has been suggested the present mouth should be protected by a detached break-water outside; but I think this, in addition to being very costly, would render the harbour very difficult to enter or

leave, and if the required smoothness of water inside cannot, as I hope, be attained by narrowing the entrance, I would much prefer an entrance in 7 fathoms at the north-east angle, in which case the corresponding outer face should be prolonged a little beyond the line of the side walls.

35. I have much pleasure in recording the cordial help afforded by the officers of the Madras Government, and by Mr. Parkes and the officers of the Harbour Works.

Note by COLONEL R. H. SANKEY, R.E, Chief Engineer, P. W. Dept.,—dated 13th March 1882.

In the annexed Report of the 9th March Mr. Parkes describes with clearness and precision he effects of the cyclone of the 12th November 1881 on the Madras Harbour Works, and although the whole of the sections cannot be completed for some little time, and may possibly, from the roughness of the sea, be delayed, there is apparently no reason on this account to defer the decision as to the further prosecution of the works.

2. As to the validity of the contentions put forward by Mr. Parkes in paragraphs 39 to 42, there can hardly be any doubt, and were his estimate for the requisite work to amount to even much more than his highest one of 18½ lakhs, it would be both desirable and profitable to complete the harbour with the least practicable delay.

3. The total outlay to date, including the revetments north of the harbour, and excluding the esplanade and jetties which are paid for from Port Funds, amounts to 59½ lakhs, but with even the large additions now proposed it would be a comparatively cheap harbour, considering that it is entirely artificial, and that difficulties of an exceptional nature have had to be overcome.

4. The revised section which by paragraph 30 Mr. Parkes proposes to give to seaward arms is almost identical in width with that of Sir John Coode's Colombo work, which, as will be remembered, was brought under the notice of Government (G. O., 8th June 1881, No. 1436W.) by the undersigned and the Master Attendant after they had visited that work early last year; and were there no other circumstances as revealed by the late storm to be taken into consideration, might be accepted as a satisfactory disposal of the matter.

5. In some respects the new section is stronger than that of the Colombo work—

(1) the vertical tenons *quantum valeat* counteract the tendency of the concrete blocks to slide on each other, and the proposed cramp between blocks Nos. 7 and 8 will give considerable cohesion to the whole;

(2) the combined new blocks, *e* and *d*, form a better top to the rear face than in the Colombo work, and

(3) the toe blocks, *f*, if closely set in the form of a continuous apron, should be a more efficient protection against the scour down the vertical face of the wall, which acted so seriously on the rubble base, than *pierres perdue* flooring.

6. It may be thought that stone tipped over the seaward face after positioning blocks *f*, would be beneficial as tending to afford a protection to the toe of these blocks, after the loosely packed rubble has been dragged outward by the action of the sea; but this is a detail which can easily be considered as the work advances.

7. It will be observed (paragraph 34) that Mr. Parkes does not intend to increase the section of the straight portions of the break-waters which were uninjured, or to do more than to feed the foreshores with heavy granite blocks and cramp the upper concrete blocks together; although, however, these portions of the work escaped almost intact on the 12th November, and though they may continue to enjoy immunity from attack for a long period, it may be doubted whether the small work to them now proposed would suffice, or that, in case his present plan be accepted, at least the addition of a properly constructed apron with blocks *f*, would not be desirable for one-third or a half of their outer lengths.

8. The proposals now put forward rest, it will be observed, chiefly upon the following considerations:—

1st.—That, as remarked in paragraph 33, "it is quite outside the limits of reasonable probability that we shall have to encounter a force of sea so much greater than that of the late storm as the strength of the new section would be greater than the old."

2nd.—That although the rubble base has subsided on an average of 2 feet and has been scoured along the seaward faces and flattened out, it has not been materially disturbed.

3rd.—That the concrete blocks at base of the wall, Nos. 1, 2, 3, and 4, remain for all practical purposes unmoved, and are in many respects even better suited for build-

ing on than before, throughout not less than two-thirds of the total length of the damaged portion of the work.

9. The first of these contentions is clearly the one upon which all must depend, and as regards this it may fairly be asked whether the storm of the 12th November supplied a sufficiently crucial test of the forces which may be expected to be called into action in a cyclone of maximum intensity.

10. Though doubtless the seas were much heavier than might have been expected from the comparatively low recorded wind pressure at Madras, as also from other phenomena connected with the storm, many high authorities would be unprepared to accept the cyclone of the 12th November as having the required character; but even as regards this storm such as it was, it is now admitted (paragraph 12) that the action of the waves extended far lower than was apparently ever recorded by engineers before in other parts of the world.

11. As observed by Mr. Parkes in paragraph 13, " This is an effect I should never have anticipated, and I can only account for it by the supposition that there is some peculiarity in the cyclone-raised disturbance to which the apparently heavier seas on the English coast have nothing analogous." He shows in fact that whereas it has been proved "by the general practice of engineers at home that 15 feet below low water is safe, *foundations at a depth of 22 feet under water are not proof against a cyclone sea* " in Madras, and adds, in paragraph 22, that near the curved portions of the break-waters, where the disturbance was greatest, "the original sandy bottom was scoured away 6 or 7 feet outside the rubble." The disturbance must thus have reached down to 35 feet below low water at least.

12. From the action of the waves during the storm the rubble in the base, which had originally been heaped up from 3 to 4 feet above the bottom of the lowest seaward block (No. 1) was lowered by that amount, plus 2 feet which these blocks sunk on an average, and in many places to the extent of undermining the block, the loose material being dragged outwards and the whole foreshore flattened. At the depth mentioned of 35 feet there seems to have been a general deepening of the sandy bed.

13. The mean level of the sea at Madras during the storm of the 12th November is shown to have been raised over 2 feet, and that sea movement reaches during abnormal disturbances to much greater depths than is commonly supposed, is proved by the recorded fact that, on the banks of Newfoundland the agitation during storms has affected the bottom at a depth of over 80 fathoms. At St. Jean de Luz it has reached to 160 fathoms, and at Lands End the labster straps are frequently filled with coarse sand and shingle during heavy ground swells at depth of 30 fathoms. Sir G. Airey mentions also that ground swells frequently break in a depth of 100 fathoms. It may, in fact, be inferred that we are in the presence of forces which cannot at present be sufficiently gauged, and the reasoning on which the monolithic system of reconstruction rests is incomplete. There is apparently insufficient ground for Mr. Parkes' contention (paragraph 24) that there is not the " slightest justification for re-opening the worn-out question of the relative merits of random and placed blocks, or of bonded and unbonded work."

14. On the contrary there would seem to be ample grounds for considering the question of adopting or rejecting the monolithic system for Madras as still open. With a bonded wall, such as that proposed, it needs but little imagination to infer what the effect would be of a succession of heavy seas (such as those shown in the plan facing page 2) precipitating themselves over the seaward arms, or how the impact communicated to the first attacked blocks would send a vibration and quiver in advance which must go far to loosen and weaken the stability of the mass—every succeeding blow shaking the structure from end to end. Even where the piers had a thickness of four blocks at the ends of the seaward arms, the impact was such as to ruin them quite as easily apparently as where there were only two blocks.

15. Again, it must be clear that the stability of a structure of this particular form must in great measure depend on whether the foundations are such as can safely withstand the scour which takes place down the face of the wall, or the disturbances due to the general cyclonic action before alluded to, which tend to drag out and flatten the material of the rubble base as during the late storm.

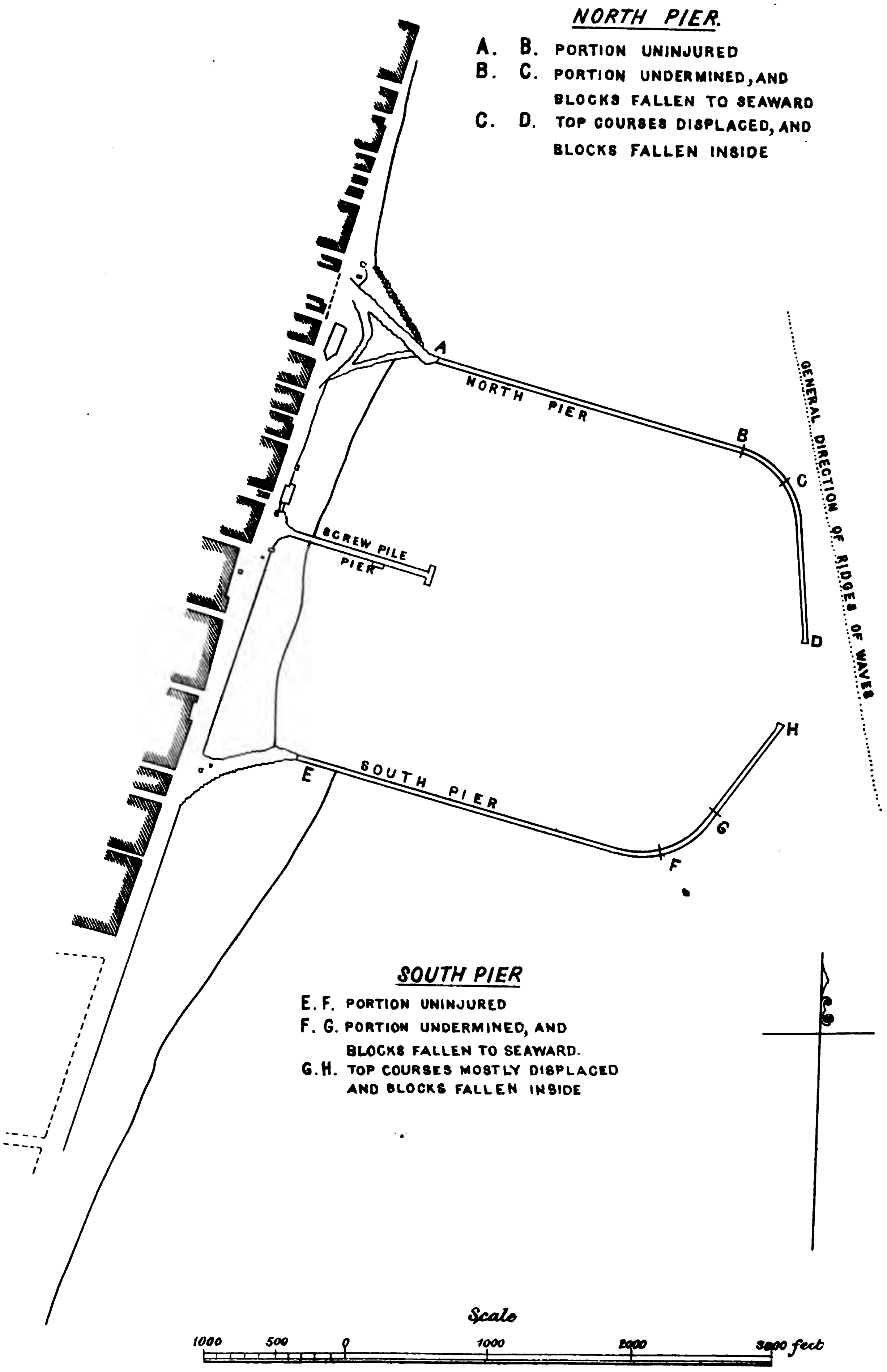
16. With a structure having its upper portion constructed of random blocks of sufficient size, the action being on the individual block, no general vibration can be communicated to the mass, and the seas must get broken up in a manner which is quite impossible with a structure on the monolithic system; the work could in fact hardly be destroyed, though individual blocks might be displaced.

17. The undersigned does not bring forward this as an original suggestion, as he was given to understand by Mr. Molesworth that, although possibly not for precisely the same reasons, the random block system was that which generally recommended itself to him. He will

MADRAS HARBOUR

SKETCH SHEWING SITES OF DAMAGE

IN STORM OF 12TH NOVR: 1881



PHOTOZINCOGRAPHED AT THE SURVEY OF INDIA OFFICES, CALCUTTA, OCTOBER 1886.

necessarily soon lay before the Government of India the results of the joint inspection of the works made lately by Lieutenant Stiffe and himself.

18. In regard to outlay, Mr. Parkes shows in his maximum estimate that about R3,20,330 and in his minimum R1,06,780 would be required for removing the broken blocks to enable him to clear the ground for his new structure, and admits (paragraph 29) that "the immense difficulty of clearing the ground of broken blocks" constitutes the "great objection" to the plan advocated by him.

19. While this trouble and expense would be saved by a system which would only aim at throwing in blocks at random when required to supplement present deficiencies and allow the sea to do the rest, it is believed that steam barges carrying shear legs could be designed on much the same principle as those used in placing the 370-ton blocks in the Dublin Quay Wall, which could be trusted to do the work economically and expeditiously.

20. With the almost ceaseless swell at Madras some difficulty may, it is true, be experienced in designing the vessels required having the needful steadiness, but with twin-barges and a proper system of guying the blocks, this should disappear, or at least be sufficiently minimised; a system of tipping might also be adopted without necessarily using shear legs. The barges could be moored close to the seaward face of the work in depositing the blocks, and could be kept in reserve after completion of the harbour for rectifying future damages—a matter of importance.

21. As more material would have to be used than in Mr. Parkes' scheme, it is not improbable that on the whole, even allowing for the savings adverted to, the expense would be greater; but without entering into detailed calculations, it cannot be supposed that the total could exceed at the outside 25 lakhs. This should include the extra apron of blocks previously alluded to for the straight portions, and also such extra dimensions to the rubble base and superstructure of blocks as may be needed to counteract the excessive action on the portions near the curves, where the damage was greatest.

22. As regards the closure of the eastern entrance to the harbour, while there can be little doubt that there is a greater disturbance of the surface within the enclosed area than was anticipated, Mr. Parkes' arguments against taking up the subject at present (paragraphs 43 to 45) appear to be conclusive.

23. In conclusion, it may be hoped that, notwithstanding the inevitable delays attending the decision regarding a question of such magnitude, there may be no cessation in the preparation of the materials required for the completion of the work. Should the random system of reconstruction be eventually adopted, probably not less than 35 or 40-ton blocks of a special shape will have to be manufactured for the most exposed portions, but for the filling in of the lower parts the present 27-ton blocks, or such others as Mr. Parkes would require for the monolithic system, would amply suffice. There should thus be no necessity to hesitate in reference to manufacturing concrete blocks of the sizes required by Mr. Parkes, or of quarrying granite for feeding the foreshores.

24. A limit of 3 lakhs of rupees might with these objects be at once appropriated for 1882-83, subject to future increment if considered necessary. As to the immediate construction of new titan cranes as required by Mr. Parkes, that must entirely depend on the decision arrived at by superior authority on the general subject of the restoration.

Report by W. Parkes, Esq., Engineer-in-Chief, Madras Harbour Works, on the damage caused to the Madras Harbour Works by the storm of 1881, dated 9th March 1882.

Madras Harbour.

I have now the honour to submit to you my report on the damage to the above works caused by the storm of the 12th November 1881, and my proposals for their restoration.

2. It has been delayed longer than I could have wished, owing to the great difficulty of obtaining detailed measurements and sections, which require an exceptionally calm state of the sea. Upon the results shown by these depend in a great measure our conclusions as to the particular action of the sea which produced the damage. I have thought it desirable to delay the submission of my report until I had obtained such facts as were necessary, not only to form a basis for my own positive conclusions, but also to test beyond the possibility of doubt the correctness of the conclusions which have been put forward by others upon a more or less imperfect knowledge of the facts. I may here mention once for all that I have given careful consideration to various suggestions that have been made to account for the damage, but I do not think it necessary to notice these as a rule, but rather to submit my own conclusions, with the facts on which they are based.

3. *Previous Reports.*—I wish, however, to explain my position with regard to two documents of very great interest, the first being a report which was made only two days after the storm by the Chief Engineer of the Presidency, who, with great promptitude, availed himself, in company with the Master-Attendant, of a specially favourable opportunity of taking what was necessarily a very general view of the state of the works. This report was forwarded "*with all reserve*" to the Secretary of State, and I had an opportunity of perusing it before I left London. If I were to comment upon the suggestions made in this report as to the particular action of the sea, it would give them a prominence which the author probably never intended they should possess.

4. The other document is a very excellent report made by Mr. Thorowgood on the 21st November, nine days after the storm, which is especially noteworthy as showing how much information can be obtained in a short time. But this information, though generally confirmed by subsequent observations, was not sufficiently complete to form a basis for practical conclusions, and what was then wanting had to be obtained with considerable difficulty afterwards. It is scarcely possible to make an intelligible statement of facts without conveying some suggestion of conclusions to be drawn from them, and in some cases such suggested conclusions fail to be confirmed by the facts subsequently ascertained. To a slight extent this is the case with Mr. Thorowgood's report, but it is no disparagement of its merits to ask that it may be considered as superseded, even if generally confirmed in its conclusions, by the present report, and in its facts by the plans and sections which will be submitted to Government, and will, I think, form a very interesting and instructive record.*

5. *Mr. Thorowgood.*—I should mention that I had the advantage of five weeks' constant communication with Mr. Thorowgood before he left for England, and during that time, as further materials accumulated, we were able to form more definite conclusions, and those conclusions, independently formed by each of us, were in all essential matters the same. They included, subject to corrections suggested by the further surveys which have since been made, most of the recommendations which I am about to submit.

6. *The storm.*—The storm is thus described in the official Meteorological Report issued by the Government Astronomer on November 23rd, 1881:—

"A cyclone visited Madras on Saturday and Sunday, the 12th and 13th instant. It appears to have exhausted its greatest force while crossing the Bay before reaching the coast of Southern India, which would account for the high and destructive sea, far beyond what might have been expected from the meteorological indications accompanying its progress. The centre of the storm must have struck the coast considerably southward of Madras. The lowest reduced reading of the barometer was 29·51 at 4 P.M. on Saturday; and the strongest wind was experienced between 11 P.M. and 2 A.M. on Sunday, during which time it averaged 32 miles per hour in velocity, equivalent to a pressure of about 5¼ lbs. per square foot. Rain commenced at 1½ A.M. on Saturday and continued until 8 P.M., amounting in all to 8·19 inches—the twelfth heaviest fall on record at Madras since 1803. No single hour was extraordinarily excessive, but the persistence of both wind and rain was remarkable. The veering of the wind was, as usual, for cyclones southward of Madras. The records of the anemograph furnish the following mid-times for each principal point of the compass with the corresponding hourly velocities:—

N. W. by W.	at 2½	P.M.;	velocity	20 miles.	E. N. E.	at 1¼	A.M.	velocity	33 miles.
N. W.	„ 3½	„ „	„	29 „	East	„ 2½	„ „	„	25 „
N. N. W.	„ 6½	„ „	„	23 „	E. S. E.	„ 4½	„ „	„	18 „
North	„ 7¾	„ „	„	27 „	S. E.	„ 7½	„ „	„	14 „
N. N. E.	„ 8½	„ „	„	30 „	S. S. E.	„ 9½	„ „	„	14 „
N. E.	„ 10¾	„ „	„	31 „	South	„ 10½	„ „	„	13 „

7. The Astronomer here alludes to the fact to which I have myself frequently had occasion to advert that there is no relation between the force and direction of the wind in the neighbourhood of a cyclone and those of the sea which may accompany it. The sea is raised, not by the wind which may happen to be blowing at the time at any given spot, but by an intense atmospheric disturbance at a distance, that is in the centre of the cyclone, and from the site of that atmospheric disturbance (which, when the wind is from the north-west at any place, will lie between north-east and east of that place) the sea disturbance will proceed, propagated by laws which, so far as we know, have no similarity whatever to those by which the atmospheric disturbance itself is propagated. On this occasion the maximum velocity of the wind at Madras was 33 miles per hour; on occasion of the great storm in May 1872 the velocity was 53 miles per hour; in May 1874 it was 49 miles per hour; while in May 1877, when the concrete block work of the north pier had advanced about 300 feet, the sea was nothing like so severe as in last November, though the velocity of the wind was 34 miles per hour.

8. The testimony of all observers is to the effect that the sea of 12th November must rank with those of the great historical cyclones, though there is a conflict of evidence as to whether

* These are still in progress. At the end of the present fine season, so much as is complete will be submitted to Government.

it was actually as heavy or heavier. Mr. Chisholm, the Government architect, a very intelligent and close observer, speaks confidently as to the recent sea being considerably heavier than that of 1872; but, on the other hand, the officers of the Marine Department, who witnessed both storms, give the palm to that of 1872. A rough test is afforded by its action on the planking of the screw pile, 17 feet above mean sea-level. This was torn up in 1872, in 1874, and again in 1881, but it is uncertain whether on the last occasion the effect of the Harbour Works would be to reduce the waves at the site of the pier (as I have no doubt was the case over the area of the harbour generally), or to aggravate them by the confusion which would be caused by their rolling in over the piers, as well as through the entrance. The end of the pier is just outside the line in which the first break of the waves occurred, and the height there was, no doubt, abnormally raised.

9. As compared with the force of sea in other places the evidence is also unsatisfactory. Mr. Bhoomya Saenna, Sub-Engineer, is the only person who could compare this sea with that raised by the south-west monsoon at Kurrachee. He considers the waves were not higher, but the succession of them was more rapid. The maximum height measured at Kurrachee was 15 feet. Mr. Chisholm estimated about the same height for the late storm at Madras,* and at both places independent testimony fixed the depth of solid water passing over the break-waters at about 20 feet.

10. Mr. Thorowgood did not consider this sea to be so heavy to all appearance as those he had witnessed at the mouth of the Tyne, and he is confirmed by Mr. Underdown, the Foreman Diver, who was also engaged on the Tyne works.

11. I do not consider, however, that these comparisons are of much value. I have given them because they are sure to be made by others, if not by myself, but my own experience is that the appearance of the sea gives very little indication of its real force.

12. *Effects of sea on foundations.*—When we come to compare results, however, we are led to a more definite conclusion. The best test for practical purposes of the force of sea is its power of undermining foundations. It is proved by the general practice of Engineers at home, that a depth of 15 feet below low water is safe. At Alderney, where there is evidence of a power of sea greater in some respects than at any place I know, foundations at that depth have never been disturbed. At Wick, where a mass of concrete and masonry of 2,500 tons was moved bodily by the sea, and the height of the waves was estimated at 42 feet, foundations at 18 feet depth were untouched, and no action was found below 10 feet. The deepest foundations I have ever heard of as being undermined were 11 feet below low water at the Tyne, but at Madras the walls were in two places for a short length *undermined at 22, feet below low water.*†

13. This is an effect I should never have anticipated, and I can now only account for it by the supposition that there is some peculiarity in the cyclone-raised disturbance to which the apparently heavier seas on the English coast have nothing analogous. There is nothing improbable in the supposition of a difference in the effects produced on the underlying water by a very intense action within a limited area, and by a long-continued surface friction over a large space. It is true that the North Atlantic storms are cyclonic in their movements, but the movements extend over a larger area, and have a less intensity than those in the Bay of Bengal.

14. But however this may be, it is certain that the 8 feet extra depth of foundation which I allowed, more for the sake of convenience and economy than for that of security, was really required for the latter purpose. Though the damage actually resulting from undermining on this occasion was not great, the whole length of the eastern face of the piers was *threatened,* and a rather heavier sea would have produced a serious amount of damage of a different kind from that which actually was produced. The most important lesson taught by this storm is that *foundations at a depth of 22 feet under water are not proof against a cyclone sea.*

15. *Effects of sea on superstructure.*—The great bulk of the damage, however, is of a totally different kind, and is due to the direct force of the waves on the superstructure. The results produced are precisely what might have been anticipated on a work of insufficient strength. The impact of the sea was delivered to all appearance just where it was expected, but it was stronger than any we had previously experienced on this description of work, and required a greater resistance than we had provided. The lesson has been very dearly bought, but it is precisely the same kind of lesson that has been taught in almost every case where works have

* Other estimates give 30 feet, but I do not put any faith on such estimates made by unskilled persons, either in respect of this or any other storm with which they may be compared.

† It is of course well known that wave action extends and even moves rubble stone to a much greater depth than this but the instances of such action have little bearing on practical engineering questions.

been undertaken exposed to a sea of unknown force. It is only when a sea of nearly maximum force has been experienced that the final precautions are shown to be necessary.

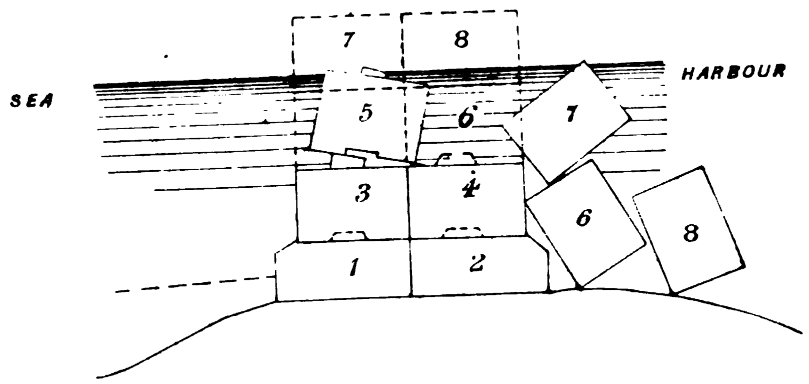
16. I believe the damage produced by this storm on the Madras Harbour Works, the general nature of which is shown on the accompanying sketch, is greater in its extent than that of any similar disaster on record, but it must not be concluded that this is due to an unusual degree of weakness in the work. It is due rather to the fact that at Madras the maximum force of sea is not, as is practically the case on the coasts where most of our experience has been gained, an event of almost annual occurrence, but it occurs only at intervals of several years, and in one such interval of more than usual duration a great extent of work had been completed, and was therefore exposed at once to the previously unknown destructive action of a sea of nearly maximum force.

17. The design of the work as executed at Madras was the result of a careful investigation into the causes of damage to previously executed works. Much material that appeared to be superfluous in them was dispensed with, but additional strength was given to the parts that were retained. The latest additions to the section were based on the experience gained at Kurrachee. At that place the first heavy sea showed where the greatest impact of the waves fell, and that part was strengthened in a way that has been quite successful in a subsequent experience of nine years at Kurrachee, and for five years was successful at Madras, but it failed under a sea of greater force than had previously been experienced at either place. To prevent a recurrence of the damage, additional strength must be given to the vulnerable part. But it must be understood that all such precautions are necessarily tentative as to their sufficiency. We may feel confident as to their being right in principle, but the force of the sea cannot be estimated in figures, and we are unable to say when a work has stood successfully, what margin of stability it possessed, or when it has failed, by how much the destructive force was in excess of its stability. The strength of an iron girder or the capacity of water channel may be definitely calculated in figures, but the stability of a sea barrier is a question to be decided by precedent, guided by judgment and experience.

18. The experience gained at Kurrachee was to the effect that the heaviest blow of the sea was delivered on the tops of the blocks on the harbour side of the break-water, tending to drive them out from the wall into the harbour. Several blocks were forced out in this way, but in no case was any block forced to seaward. The tendency was met by inserting a stone joggle, which blocked the top course to the course below, and prevented it from sliding. This precaution was quite successful at Kurrachee, and a contrivance for effecting the same object having been from the first adopted at Madras, the tendency was so completely met that no evidence of its existence was given by the action of the seas which preceded that of the 12th November last.

19. A knowledge of this tendency, however, forms a clue to enable us to trace the process of destruction of the Madras piers. The waves rising upon the sea-face must have fallen with terrific force upon the top of the work on the harbour side, and the blocks were tilted off, probably two courses, and possibly, in some cases, three courses, being displaced at once. The sea-wall then standing alone yielded to the lateral force of the waves, and generally one course, but sometimes two, and in one or two cases even three, courses were driven after the blocks of the harbour wall. Generally speaking, there is a course more remaining on the sea-side than on the harbour side.

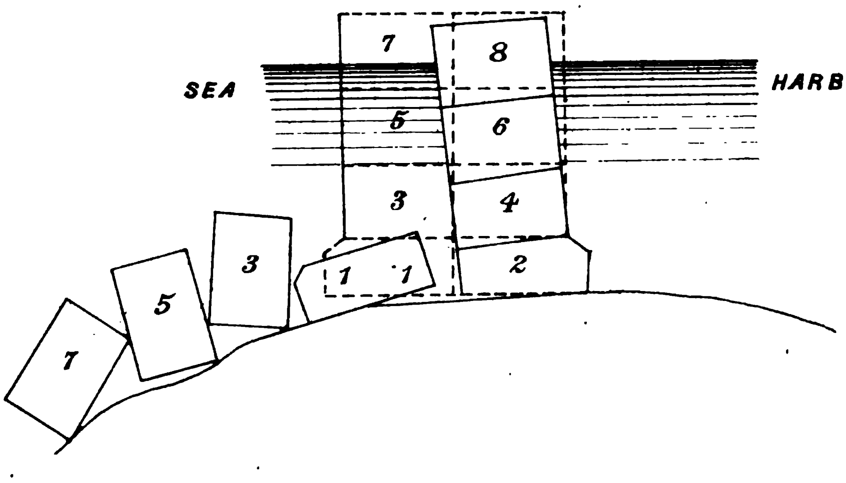
20. The following may be taken as a typical section of very much of the work in its present state :—



Parts of it are necessarily hypothetical, but there is enough which is matter of actual observations to justify the assumption of the remainder. For a length of at least two-thirds of the damaged parts, blocks 1 and 3 have been traced by the divers and found with slight exceptions to be undisturbed. For the greater part of this length block 5 may be traced from the surface and sometimes from below, generally more or less disturbed, somewhat in the way shown. No. 7 is in some cases in its place, but it is then generally tilted by riding on the tenon on the top of No. 5; 6, generally 7, and 8 are represented by an apparently confused heap of blocks which effectually prevent access to 2 and 4. There is, however, sufficient evidence, direct and indirect, to negative the very improbable supposition of these having been undermined and thus caused the fall of the inner wall towards the harbour. This evidence is, first, that where the inner slope of the rubble is unencumbered with blocks it is found to be practically unchanged; second, where the sea-wall is gone and the harbour wall standing, as is the case for a short length in each pier, the harbour wall leans over to seaward; third, at the spot at which, if anywhere, scour under the harbour wall might be expected, *viz.*, at the extreme end of the north pier the rubble is 4 feet above the foundations, and the wall is standing exceptionally well, the blocks corresponding to No. 6 being in place. There can therefore be, I think, no doubt that the failure began with No. 8 block, or more probably 6 and 8 together, and worked downwards and towards the harbour. The rubble foreshore on the sea-sides, however, presents a marked contrast to that on the harbour side. It is almost everywhere drawn away from the wall and lowered sometimes below the level of the foundation blocks.

21. The above description may be taken as a generalisation of the effects produced upon about two-thirds of the damaged parts. It comprises the outer portions of the two piers, a length of 1,200 feet of the north and 900 feet of the south pier. The remaining third, comprising 400 feet of the north and 500 feet of the south pier, have been differently affected, and the investigation is more difficult, as the blocks are thrown down on both sides of the piers, and a precise examination of the portions which remain standing is for the most part impracticable.

22. There is, however, one portion of the north pier, just at the commencement of the curve, which is accessible to the diver, and has been carefully examined. The following section made from his description will very clearly exhibit the action to which it has been subjected. In this case the harbour wall is standing, though considerably damaged.



No. 1 block is drawn out to seaward 4 feet from its original position, and its inner end is lifted 9 inches from the rubble bed, the block itself being tilted towards the sea. The upper blocks are lying in confusion on the sea-slope of the rubble. I do not see how it is possible to attribute these results to any other action than undermining of the foundation blocks. The portion of the pier where this is evident is a length of something under 100 feet, but it is probable that whenever the upper blocks have fallen to seaward, it is due to the same cause, although the foundation blocks themselves are inaccessible. The action of the sea appears to have been exceptionally severe at this spot, for the original sandy bottom is scoured away 6 or 7 feet outside the rubble.

23. There is a portion of the south pier, also on the curve, which appears to have been acted upon in a very similar manner. At these two places the break-waters form about the

same angle, one on the right and the other on the left, with the prevailing line of the waves, and here the scouring action on the bottom appears to have been more violent than where the waves fell more directly on the face of the work.

24. *Remedies.*—The whole of the actual damage to the works is due to one or other of the above causes, and I think that if the original section were amended so as to give increased strength to the two weak places shown to exist, every confidence might be placed in its stability under even a much heavier sea than the recent one. The section as carried out was a perfectly good one to withstand a moderate sea, and the effects of the heavier sea show no grounds for any radical alteration. Such material as there was was good in quality and properly disposed, but there was not enough of it; or perhaps it would be more correct to say the principles of the design were good, but not carried far enough. There is not the slightest justification for re-opening the worn-out questions of the relative merits of random and placed blocks, or of bonded and unbonded work. Break-waters of random blocks, or of bonded masonry, might have stood if very much more massive than those which have partially failed, but their security would have been due to their greater massiveness, not to the different principles of their construction.

25. *Quality of Materials.*—I have said that the materials were good. I am aware that a great deal has been said about the unsuitableness of laterite for the rubble base, and some doubts have been expressed about the quality of the concrete owing to many of the blocks having been broken. Now, laterite is undoubtedly a *troublesome* material, and I am glad to think that no more of it will be required, but there is not the slightest ground for thinking that it contributed in any way to the late disaster. The trouble it occasions is that, being friable, it is very quickly compressed by the weight of the blocks laid upon it, so that to allow for subsidence the latter have to be set a higher level than is ultimately required. This is troublesome in execution, and it has the still greater evil of subjecting the blocks to excessive and irregular strains in the process of subsidence, in consequence of which many were broken. But when once consolidated, the laterite forms as good a bed as the granite rubble. This is proved by the comparison of the amount of settlement of the standing portions of the two piers, one being built on laterite and the other on granite. There is no appreciable difference between the two. It is right to add that the laterite was used, not from choice, but because it was not practicable to obtain the granite rubble in sufficient quantity to carry on the work at the speed for which all other parts of the work were organized. It would, of course, have been right to sacrifice speed of execution if ultimate stability were endangered, but after full consideration it was decided that this was not the case.

26. *Breaking of Blocks.*—The breaking of the blocks is undoubtedly a blemish, and, though it occurred over both the granite and laterite bases, it occurred, I have no doubt, more over the latter for the reason I have given above, though it is impossible to determine the proportions accurately. The evil, however, is really greater in appearance than in reality, for the force which broke the blocks at the same time jammed them so closely together that the broken pieces are really as effective for the stability of the work as many unbroken blocks which have not been subjected to the same amount of pressure. I doubt whether it would have been possible by any means entirely to prevent these breakages, but the number would have been reduced if it had been possible to keep the blocks longer before subjecting them to these severe strains. Be this as it may, however, the concrete is undoubtedly of excellent quality, as even the fractured surfaces of the broken blocks show. In the restoration of the work, as I shall presently point out, this evil will not recur. But so far there is no evidence to show that these breakages have contributed in any way to the failure of the work.

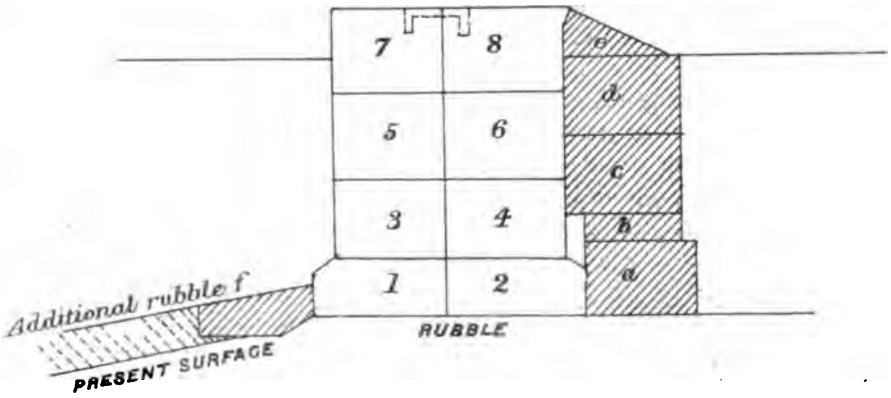
27. *Subsidence.*—Another point which has given rise to a good deal of remark is the subsidence of the structure, but in this I can see no evidence of weakness. It is quite certain that a rubble bank, 20 feet high, must consolidate under the weight of 30 feet of concrete, and it is equally certain that the effect of agitation of the water must be to cause the rubble to sink into the sandy bottom, but beyond involving the necessity of adding to the top if it sinks below the required level, there is really no harm done. We have the experience of years to show that subsidence does not involve loosening of the superstructure, but rather the contrary, while the sinking of the foundation to a still lower level is a substantial advantage. The portions of the piers standing entire have settled under the action of the storm about 9 inches at their outer ends, gradually diminishing to nothing near the shore, the amount of sinking being inversely proportioned to the length of time since they were built. The damaged portions, which of course are newer, have sunk about 2 feet, as far as can be ascertained. There may probably be a further subsidence, though its rate will decrease as time goes on, but it is, I repeat, a perfectly harmless process. The above are the settlements due to this particular storm. There had been previous settlements due mainly to the natural consolidation of the

rubble base, generally amounting in the aggregate to from 2 to 3 feet, the maximum being near the south pier head, where it was 4 feet. The further settlement due to the storm is probably caused by subsidence into the sandy bottom.

28. *Reconstruction.*—In the scheme for reconstruction, then, we have especially to keep in view the two weak points, the foot of the outer wall and the top of the harbour wall. The required object may be attained either by breaking the force of the waves before they reach the weak points or by giving additional strength to the weak points themselves. The former principle has received full consideration. It appeared at first sight that the remains of the original piers would form a good outer barrier under shelter of which a new pier would be safe from damage. But further examination was not favourable to this idea. The shelter it would give in its present state is too irregular. In some parts it might be fairly efficient, but in others it would allow the sea to pass over it on to the new work with increased violence. To prevent this such places would have to be made up with new material, and this would lead to a serious amount of work, and I think a not very satisfactory result. Besides which there is a considerable porportion of the old work remaining, and the rubble base especially, having been well consolidated, would offer a better foundation than a new one, especially in not being liable to the immediate settlement which caused the fracture of the blocks. Two out of the four courses of blocks are also for the most part in good state, and an uncertain proportion of the displaced blocks may be recovered and used again.

29. Preference was therefore given to the principle of rebuilding the piers on their original foundations, and making such additions as experience shows to be necessary. The one great objection to this is the immense difficulty of clearing the ground of fallen blocks. The magnitude of this difficulty can hardly be realised without inspection of the ruins. It will undoubtedly be a slow and costly operation, but all who are concerned in it are satisfied of its practicability, and, the difficulty being simply a mechanical one, we may safely conclude that it will diminish with practice and experience.

30. I propose, therefore, that the work be rebuilt on the former lines and to the former section, but with the additions shown shaded on the accompanying sketch, to give increased strength to the two weak points.



The rubble base and blocks 1, 2, 3, and 4 are generally in a serviceable state. 5, 6, 7, and 8 are new blocks similar to the old ones, except that they will be 9 feet high instead of 8 feet, so as to make up for the 2 feet of subsidence *a*, *c*, and *d* being of the same dimensions as the old blocks, the latter can be used so far as available; *b* is a thin block inserted for the purpose of bringing the top of *d* above water level, so that *e* may be set upon it in a bed of cement, thus making *d* and *e* together into one block of 36 tons weight. The top of *e* is sloped off to give an escape for the falling wave. If it were level like the top of 8, the effect would be simply to transfer the vulnerable point from the top of 8 to the top of *e*, as is shown by the fact that at the pier heads where the structure was increased to three and four blocks in width the one next the harbour still gave way.

31. Block *f* is intended to protect the toe of the outer wall from scour and ultimate undermining. It should be placed at as low a level as practicable, so as to avoid encroaching on the profile formed by the sea itself. It is a noticeable feature in the cross sections of the damaged parts of the piers that a scanty slope of rubble and severe damage to the superstructure do not go together. On the contrary, where the sea-wall was actually undermined at the south pier, and the nearest approach to a clean breach was made, the rubble base happened to be particularly full. The evidence is at present not more than negative, but it is to the effect that a full fore-shore is not an element of strength. The object of the footing, therefore, is simply to substitute a surface of concrete for one of loose rubble, preserving as nearly as possible the level and slope which the sea has formed. From the outer end of the block the slope will be continued in rubble. It may probably be desirable where the blocks are fallen to seaward not to disturb them, but rather add some more so as to make protective mounds of random blocks at those places.

32. Besides these actual additions to the section, I propose to introduce two extra securities into the top course of the old section. It has always been an object, though hitherto unattainable, to connect the top blocks together, both longitudinally and transversely, so as to make all the portion of the section which is out of water into a monolithic mass; but it is impossible to do this in new work efficiently in consequence of the settlement to which the structure is liable. An unequal settlement would sever any attachments we could apply. Now, however, in rebuilding on an old foundation this difficulty will be much diminished. What settlement does occur will be more uniform, and slight inequalities in it may even be prevented by the adherence of the attachments. It is proposed, therefore, so to make the cross joints of the top blocks that they may be filled with cement, not during the progress of building, but on a suitable opportunity afterwards. It is also proposed to connect the two top blocks by an iron cramp made of a bent, worn-out rail with the ends turned down and cemented into the blocks. Thus, each longitudinal row of blocks will become, so far as the cemented joints can be depended on, a monolith, and the two monoliths will be tied together at intervals of 4½ feet. It cannot be anticipated that the monoliths will be absolutely continuous. Some of the cement joints will separate, but the majority will hold together, and the top of the break-water will consist of much larger masses than hitherto, which will lend support to one another in a way that the detached blocks could not do.

33. The section thus modified would have the following additional elements of stability over the old section :—First, it would have 50 per cent. greater width as a whole. Second, the vulnerable block No. 8 would be supported (*a*) by a buttress one-third heavier than itself, (*b*) by a tie to block No. 7, (*c*) by its longitudinal continuity afforded by the cemented joints. Third, the toe of the sea-wall would be protected from undermining by an apron of concrete blocks. I must repeat that it is impossible to show the sufficiency of this by figures, as the force of sea is an indeterminable quantity. But I think it quite outside the limits of reasonable probability that we shall have to encounter a force of sea so much greater than that of the late storm, as the strength of the new section would be greater than that of the old.

34. *Uninjured Portions.*—I do not propose that the additions to the section should be applied to the portions of the piers which have stood uninjured. They have shown no sign of weakness beyond some scouring away of the foreshores at the foot of the sea-walls. These should be fed with some heavy granite boulders. It would be desirable, however, now that the block work has settled down to a solid bearing, to tie the top blocks together with iron cramps in the same way as described for the new work. This would give additional resistance to block No. 8 in the event of the next heavy sea coming from a point more northerly or more southerly than the last, and the cost would be small, as there are a great number of rails which are of no value for any other purpose.

35. There is one further additional security which I would propose to apply to the curved portions of both piers. These have a special element of weakness in the fact that if there should be any leaning over to seaward, the upper course of blocks would open out like a fan. The late storm showed that there is a greater scouring force on the foreshore of the curves than elsewhere. I hope undermining from this cause will be effectually prevented by the precautions above recommended, but I would propose, as an additional precaution for the support of the superstructure, to form a groove longitudinally along the top of the sea-wall about 12 inches deep all round the curves, in which a strong chain cable will be laid, strained up tight and then buried in concrete. The whole curve would thus be bound together.

36. I would beg to call attention to the fact that each one of the additions I have recommended is intended to meet some weak point disclosed by the action of the sea upon the work. I have made no attempt to meet theoretical objections that are not supported by the special experience of this particular occasion. My object has been to preserve what experience has

shown to be good in the work, as well as to supplement what was shown to be insufficient, and I submit that it is by this process, rather than by radical changes of plan which would involve much experimental work, that ultimate success will be best assured.

37. *Estimate.*—In endeavouring to form an estimate of the cost of the works of restoration, I am met at the outset by elements of great doubt. About 43,000 cubic yards of concrete block work has been displaced. If the blocks were recoverable in an efficient state, they might be reset in position for about 4 lakhs of rupees, but it is quite certain that many are broken, and these will be more costly to remove than the unbroken ones, and will have to be replaced by new ones. To replace a broken block will cost altogether about three times as much as to reset a sound one. Others again, though unbroken, will probably be so jammed into the confused mass that they can only be removed by blasting them to pieces. Now, it is quite impossible to form a reliable estimate of the proportion of blocks available for future use. One-fourth and three-fourths may be taken as the limits of uncertainty in the matter. As the work of restoration advances, a more definite estimate may be formed, but for the present I am really unable to do more than give the minimum and maximum of what may fairly be taken as within the limits of reasonable probability. The Government will, no doubt, think it right to take the maximum estimate as the basis of its deliberations. I may be permitted to take the minimum as what I hope to see realised, though I am unable to pledge myself to it.

38. I have therefore divided my estimate into two parts: the first part is for the restoration of the work to its former state, exclusive of the small portions of the original design remaining incomplete, and the question of ultimately completing which should remain for the present in abeyance. The second part is for the additional works of strengthening recommended. The first part is also presented in two alternatives—a maximum and a minimum—the former amounting to a little under 9 lakhs, and the latter a little over 6 lakhs. The second part is basedon the prices at which the work has hitherto been carried on, and may therefore be taken as reliable. Its total is a little over 9 lakhs. The total cost of placing the whole work in an efficient state may therefore be taken as lying between the limits of 15¼ and 18¾ lakhs, and I think three years will be required from the time of recommencing building operations for its completion.

39. The second part of the estimate (that for new works) is the amount which would have been added to the original estimate if we had had the data necessary for making provision against the force of a cyclonic sea. The first part is the penalty paid for our ignorance on this point. But I may remark that this is not altogether without its equivalent. If the work had been carried out in the first instance in its stronger form, its completion would have been delayed by two years, and for those two years the harbour would have been in a less efficient state than it is now with the damaged piers.

40. *Present efficiency of the Harbour.*—Indeed, the business of the harbour has proceeded with scarcely any change in consequence of the accident, and although steamers have the option of saving the payment of extra dues (levied according to the present admittedly inequitable system of charging on the register tonnage instead of on the cargoes landed and shipped) by anchoring outside, they invariably submit to the grievance and come in. The injury to the harbour is scarcely felt during fine weather, when the great bulk of the landing and shipping operations are carried on. Its evil effects will be felt in moderately rough weather, when more sea will come into the harbour, though even then the damaged piers will be better than none.

41. With the view of ascertaining what is the amount of benefit at present afforded by the harbour, I obtained, by the courtesy of the Collector of Customs and of the Agents of the principal lines of steamers, returns of the number of vessels of all classes which have visited the port for the three months following the accident to the harbour works and of the number of tons of cargo actually landed and shipped within the harbour during the same time. The total register tonnage of sailing vessels was 13,302, and I have not ascertained what quantity of cargo was landed and shipped by these. They all lay outside the harbour. The register tonnage of steamers was 146,374, and the quantity of goods landed about 22,000 tons, and of those shipped 11,000 tons, making a total of 33,000. As the whole of this work was done at a rate of boat-hire less than that chargeable in the roads of half a rupee per ton, the sum of R18,000 represents the proper earnings of the harbour during the first three months llowing the storm. I put the matter in this way rather than by giving the actual amount levied as dues on the register tonnage, because the latter does not represent the amount of business done in the harbour, and is in force only pending arrangements for a more direct and equitable mode of making the charge. The half rupee per ton also will be raised, when the harbour and the landing and shipping arrangements are more complete, to one rupee, and of course extended to the cargoea of sailing vessels.

42. I submit, therefore, that the Madras Harbour, even in its present damaged and incomplete state, is by no means an unprofitable undertaking. It is confessedly imperfect, and there are other points requiring consideration besides the restoration of the works, to one of which it is desirable to allude.

43. The experience gained since the harbour piers approached completion is to the effect that the entrance facing the eastward admits an amount of swell (particularly with easterly seas, which are more frequent than was supposed) which will render it desirable so to arrange the berthing of ships that they may lie with their heads towards the in-coming swell, instead of towards the prevailing winds, as had been at first intended. For the great majority of days in the year this can be done without difficulty, but there are occasions, about 25 to 30 days, as estimated by the officers of the Marine Department) when a ship cannot lie with her broadside directly or even obliquely exposed to the wind. On such occasions it becomes necessary to cast off the stern moorings and allow her head to swing to the wind. As the ship will then roll to the swell, landing and shipping cargoes will be more difficult, and sometimes even prevented. With a strong wind from one direction, and heavy swell from another, the ship would roll very uneasily, and though it might be only in extreme cases that she would be in actual danger, such danger could only be avoided by sending her to sea. This in itself is no unforeseen contingency, but it is now suggested that there would be a difficulty in getting a ship clear from such an uneasy berth as that just described while subject to the combined influence of wind and swell. This difficulty could only be avoided by an earlier anticipation of the danger, and by taking the ship out of the harbour at an earlier period of threatening bad weather.

44. The officers of the Marine Department are of opinion that this evil can only be effectually cured by closing the present easterly entrance and making an opening facing southwards in the south pier. If I do not enter into the merits of this proposal, it is not because I question the reality of the evil, but because I think it premature to discuss a question upon which no practical action could in any case be taken for the three or four years that will be required for the restoration of the damaged portions of the piers. During those three or four years the harbour will be in daily use, and the bearing of this one particular evil upon the whole question of the development of the advantages afforded by the harbour will be more easily seen. It is not a question of a harbour, or no harbour, but of a harbour affording a greater or less degree of shelter, and the value of the increased shelter will be more precisely ascertained by the experience of actual work. The proposal may then be put forward (if its desirability be confirmed by experience) as one giving an advantage directly comparable with the cost.

45. So far as carrying out the alteration is concerned, nothing would be gained by an immediate decision; nor do I think, even if the idea had been entertained from the beginning, any materially cheaper plan could have been devised—certainly none more expeditious—than that of advancing both piers to near their meeting point, using the interval between them as a temporary entrance, and then making the final opening in such a position as might appear most desirable by drawing back one of the titans, removing the necessary length of blocks, and dredging away the rubble. The materials, of course, could be used for the final closing of the original entrance, which would be carried on by the other titan from the side opposite to that in which the new opening would have been made. This process will still be available if the alteration be ultimately determined on.

46. Having now explained as clearly as I could my views with regard to the present state of the works and the best mode of restoration, it remains only for me to specify the immediate action required for carrying my recommendations into effect. An urgent indent should at once be made for two new titan cranes, to be constructed with such modifications, from the pattern of the former ones as is necessary for the altered circumstances of the work. I shall be prepared to furnish the details of these immediately on receiving instructions, also 2,000 tons of the Portland cement should be immediately ordered—1,000 tons to be shipped by canal steamer, and 1,000 by sailing vessel. Other stores and materials will be required from England, for which indents will be duly submitted by the Superintendent.

47. In the meantime block-making should be proceeded with with the cement now in stock and such as may be procured from the local manufactory (formerly General Morgan's). The cramp irons described in paragraph 32 *ante*, should be fixed in the uninjured portions of the piers, and the inequalities in the tops of the blocks levelled up with new concrete. This last is a small work which could not be carried on while there was a constant traffic on the piers, but may now be conveniently completed. The foreshores of the standing portions of the piers should also be made up after the cross sections have been taken to show exactly what is required.

48. I propose to submit a separate report on the question of the beach improvements and landing jetties which were sanctioned a year ago, and partially carried out, but the whole scheme must be reconsidered under the present changed conditions. These works are not charged to the Harbour Works Grant.

MADRAS HARBOUR.

ESTIMATE OF RESTORATION.

PART I.—REPAIRS OF DAMAGE.

	R	a.	p.	R
Maximum—				
New Plant and Machinery				1,25,000
Resetting existing blocks of second course, both piers, 21,355 cubic yards, at	2	0	0	42,710
Removing broken blocks, 32,033 cubic yards, at	10	0	0	3,20,330
Replacing 32,033 cubic yards at	10	8	0	3,45,956
Recovering whole blocks, 10,678 cubic yards, at	4	0	0	42,712
Resetting do., 10,678 cubic yards, at	2	0	0	21,356
				8,98,064
Credit by 32,033 cubic yards available as rubble, at	3	0	0	96,099
				8,01,965
Establishment (7½) and Contingencies (2½)				80,196
				8,82,161
Minimum—				
New Plant and Machinery				1,25,000
Resetting existing blocks of second course, both piers, 21,355 cubic yards, at	2	0	0	42,710
Removing broken blocks, 10,678 cubic yards, at	10	0	0	1,06,780
Replacing 10,678 cubic yards, at	10	8	0	1,15,322
Recovering whole blocks, 32,033 cubic yards, at	4	0	0	1,28,132
Resetting do., 32,033 cubic yards, at	2	0	0	64,066
				5,82,010
Credit by 10,678 cubic yards, available as rubble, at	3	0	0	32,034
				5,49,976
Establishment (7½) and Contingencies (2½)				54,998
				6,04,974

ESTIMATE OF RESTORATION.

PART II.—SUPPLEMENTARY, STRENGTHENING WORKS.

	R	a.	p.	R
North Pier—				
Buttress wall, 22,504 cubic yards, at	10	8	0	2,43,043
Apron outside, 4,000 cubic yards, at	12	9	0	51,600
*Extra rubble outside, 36,000 tons, at	2	0	0	72,000
* Ditto inside, 20,952 tons, at	2	0	0	41,904
Two feet extra height, 3,111 cubic yards, at	10	8	0	33,598
Cementing joints of top course, 218 cubic yards cement mortar, at .	30	0	0	6,540
Bending and fixing cramp irons				10,000
Chain round curve				1,500
Levelling top of blocks on standing portion				10,000
South Pier—				
Buttress wall, 17,735 cubic yards, at	10	8	0	1,91,538
Apron outside, 3,200 cubic yards, at	12	9	0	41,280
*Extra rubble outside, 31,200 tons, at	2	0	0	62,400
* Do. inside, 16,512 tons, at	2	0	0	33,024
Two feet extra height, 2,400 cubic yards, at	10	8	0	25,920
Cementing joints of top course, 167 cubic yards cement mortar, at .	30	0	0	5,010
Bending and fixing cramp irons				10,000
Chain round curve				1,500
Levelling top of blocks on standing portion				10,000
				8,50,857
Establishment 7½ per cent. / Contingencies 2½ „				85,086
Total cost of New Works .				9,35,943

Note by COLONEL H. A. BROWNLOW, R.E., Inspector General of Irrigation, on Mr. Molesworth's report,—dated 3rd April 1882.

In the opinions expressed, and recommendations made, by Mr. Molesworth, I concur most fully; but, having regard to the enormous forces which may during the occurrence of a cyclone be brought into action against the harbour faces, and to the extreme inadvisability of creating distrust in the stability of the work during a storm, I would increase the section shown in diagram opposite to paragraph 16 of his report by increasing the number of blocks used in the random block section to, say, 10½ per 4½ lineal feet. I think, also, that it would be well worth while to incur extra expenditure on increasing the *specific gravity* of the blocks laid on the outer face of the new work. In 1870 I visited the works in progress at Tynemouth for improvement of entrance of the river and found the foreshore being protected by concrete blocks of great density and tenacity, consisting of furnace refuse (containing 60 per cent. of iron) mixed with Portland cement in the proportion of 6 to 1; 12 cubic feet of this mixture weighed 1 ton,* and 36-ton blocks made of it were found necessary to resist the force of the waves, estimated at 5,000℔ on the superficial foot in heavy storms. At Tynemouth it was also found that the waves flattened out the rubble deposited below low-water mark to a maximum width of base equal to about ten times the depth (300 feet base for 30 feet depth), so that I anticipate the ultimate necessity for considerable additions to the rubble bases on sea-faces of the Madras harbour, unless they are protected by additional blocks towards the sea, such as I have recommended. Taking all things into consideration, I think that 35 lakhs of rupees will most probably be found nearer the ultimate cost of efficient restoration of the harbour than either 27 or 30 lakhs.

* The ordinary blocks of the Madras Harbour works measure 12 feet × 8 feet × 4½ feet, and weigh 27 tons, so that 16 cubic feet of block weigh 1 ton. Blocks of the same size, but of density similar to those used at Tynemouth, would weigh 36 tons.

From CAPTAIN J. H. TAYLOR, R. N. R., Master Attendant, Madras, to the Secretary to the Government of Madras, P. W. Dept., on the force of the sea against the Madras Harbour Works during the storm of 1881,—No. 2682, dated 4th April 1882.

I have now the honour to remark that, having carefully attended to various remarks upon the damage done to the harbour, and the means recommended for its restoration, I feel it my duty respectfully to draw the attention of Government to a most important feature in the case, upon which it seems to me considerable and dangerous misapprehension is likely to exist, *viz.*, the comparative strength of the sea upon the occasion. Few officers have had more opportunities than myself of observing cyclones and estimating their wave action, and I have always said that the attack upon the works on the 12th November was a very mild one, and not calculated to furnish a proper basis for reconstruction. I have now the honour to forward reports from the experienced officers of this Department and the boatmen of the port, by which it will be seen that no difference of opinion exists upon this important point. It will be a real calamity if another disaster follows from want of appreciation of the difficulties nature may again throw in the way. I have had my attention drawn to several theories about cyclone waves, but they do not recommend themselves to me as trustworthy when such important interests are at stake.

2. The random block system is the only one that, as far as I can discover, has the confidence of the public. Had this method been adopted directly the accident occurred, the work would have now been six months advancing towards completion. Stone, such as was used by DeHavi land for his bulwark (which stone still remains *in situ*) and by Sir A. Cotton for his break-water, is to be found in abundance in the bed of the Adyar, close to the South Indian Railway.

3. I regret to notice the small attention attached by Mr. Parkes to the question of the eastern opening. The harbour will not be efficient while that is allowed to remain.

4. The suggestion of a small beach boat harbour, though it might do much good, does not seem to take into consideration the insanitary condition such a work would soon fall into, nor its great expense. At present the seas that come in and over the walls heap up water in the harbour, beating upon the beach with more or less violence, and taking up all deposits, and by the aid of the strong current setting outwards, of which they are the original cause, keep up a cleanly and healthy state of things, which, in my opinion, it would be a pity to disturb.

Memorandum by T. E. MARSHALL, Esq., Deputy Master Attendant, Madras, on the same subject,—No. 910, dated 30th March 1882.

Having been asked by the Master-Attendant to record my opinion regarding the relative height of the seas during the cyclones which prevailed at this port on the 2nd of May 1872 and the 12th of November 1881, I have no hesitation in stating my solemn conviction,

from careful personal observations during both cyclones, that a much higher and fiercer sea prevailed in the storm of May 1872 than in that of November 1881.

In making this comparison I am of course particularly referring to the sea and surf outside of the walls of the harbour. The sea inside the harbour was not a natural sea; it was a pyramidal bubbling boiling sea; in fact, one may call it an *artificial* sea. The pyramidal form of wave being in a great measure owing to the great volumes of water which were brought into the harbour by the wind and sea through the easterly entrance, and also by the heavy seas, some of them 50 feet long, topping the harbour wall, finding a vent by running out to seaward through the easterly entrance and *against* the easterly sea. It is now an ascertained fact that during a cyclone there can only be an *easterly* sea prevailing within the harbour walls, no matter from which point of the compass the wind may be blowing.

To revert to the hurricane sea outside, *i.e.*, the cyclonic sea proper, I find it recorded in my notes of the May cyclone, "at daylight the roadstead was an object worth seeing. As far as the eye could reach, between the lulls, the sea out to 9 fathoms of water was a roaring mass of breakers; the shipping at anchor were completely enveloped in spray, the rollers breaking clean over their bows and dashing wildly up to their lower mast-heads." I now state that no such sea prevailed on the 12th November last. The sea did not break in 9 fathoms of water. Had such sea prevailed, the barque *Mars* would have been inevitably lost, instead of being able to go to sea in ballast trim, under doubled reefed topsails and reefed foresail. The heaviest sea prevailed between daylight 6 A.M. and 8 A.M. of the 2nd May 1872, when but very few of the citizens of Madras were out of doors. It was *at this time* that the port was placed on the *advancing* quadrant of the storm, and *nearest* to the centre, before its contact with the shore. At 9. A.M. the wind was east and the vortex had passed inshore and over Madras, and the extreme violence of the sea had abated in force, though it still continued very violent until noon.

In further confirmation of the heavy sea of May 1872, I would here state that I was an eye-witness of the loss of the *Ardbeg* of 925 tons register. She struck well outside, being deeply laden, and disappeared entirely within the space of two minutes. This ship was simply to my view *engulfed*, as she lay on the ground, by a tremendous sea, the height of which, in my humble estimation, could not have been less than 20 to 30 feet in height.

It has been alleged that the sea in a cyclone need not necessarily be high or low according to the force of the wind, and that in the last cyclone, although the wind blew with but comparatively little force, yet there was a greater sea on as compared with the sea in 1872. This *may* be the case on some occasions. For instance, we know that the sea in the advancing quadrant of a cyclone when near to the vortex is much heavier than the sea further away from the vortex. We know that the sea immediately behind or in the wake of the vortex is a very violent cross sea, when perhaps the wind has considerably lulled. But in taking into consideration the force of the wind in the last gale, it seems to have escaped notice that the *strength* of the gale was from *N.W.*, or off the land, and that therefore the sea could not possibly be very heavy. In the May gale of 1872 the wind for four days had no westing, *but all easting*, in it—a most important factor in *raising a sea*. The last cyclone came in upon the shore on a N.W. or W.N.W. course; the storm in 1872 ran nearly parallel with the coast for about 48 hours, which was abnormal, and which, combined with the slow rate at which the vortex travelled, helped materially to raise a tumultuous sea with which that of November last should not be compared.

Finally, I would state that, in my opinion, the *average* height of the waves in the May cyclone of 1872 was not less than 15 feet.

Memorandum by W. H. BARTLETT, Esq., on the same subject,—dated Madras, 31st March 1882.

I am of opinion that the sea outside in the cyclone of 2nd May 1872 was much heavier than that of 12th November. In the former case, in the very early part of the day, and when only a few people were out of their beds, or on the beach, the wind and sea were both coming in from N.E., and, acting conjointly, produced such a sea as I have seldom seen.

The *Ardbeg*, a loaded vessel of about 1,000 tons, parted or slipped from her anchor, and, failing to get an offing, she took the ground broadside on, and in less than two minutes there was not a vestige of her to be seen.

A little later on the *Burlington*, about half loaded, came ashore to the southward, also broadside on, and in a very few minutes she parted amidships.

Later on in the day other ships came ashore, but by about 9 A.M. the wind went round to the southward of east, and, as a natural consequence, the sea went down.

It was from this time that people began to assemble on the beach. This is a very important factor in comparing the seas on the two occasions in question, as those who witnessed the

state of things at 9 A.M., and later on, could not possibly form a correct estimate, the worst of the weather being then over.

In the height of the cyclone the *Evelyn*, which was lying much inshore of the *Inverness*, and consequently had a more perilous position, cut away her main and mizen masts, and she even then dragged considerably to the W.N.W.

Some stress has been laid on the fact that the *Inverness* and *Bonnie Dundee* rode out the cyclone. True they did so with a long scope of cable, and in 10½ fathoms water, but very wisely neither of them attempted to put to sea, while in the rough weather of last November the *Mars* put to sea without difficulty, under an amount of canvas which would have insured her capsizing had she attempted to do so in the cyclone of May 1872.

From MR. C. STOLBERG, Pier Master, Madras, to the Master Attendant, drawing comparisons between the storm of 1881 and those of previous years,—No. 182, dated 31st March 1882.

In accordance with your order, I have the honour to submit my humble opinion with reference to the cyclone in 1872 and the rough weather in November last.

2. The cyclone of 1872 was a very severe one. I can only equal it to those hurricanes that blow off Mauritius and Cape Hatteras, in which it is impossible to face the wind. It was so in May 1872. About 8 A.M. it blew the strongest, and most of the ships parted their cables. Captain D. Foreman, of the Ship *Invershire*, told me that the sea broke over his ship in 8½ fathoms of water when his cable parted. The pier suffered a great deal during 1872 cyclone; most of the sleepers were washed away; several beams torn away from the pile caps owing to the very high sea which prevailed, whereas in November last the wind and sea were nothing like it. I was on the pier for most of the day, and up to noon boats were plying between some of the lighters and the pier. I saw the harbour titans fall; at the time the sea was nothing to speak of to what it usually is during rough weather. In the afternoon the sea got worse and the wind increased to a gale. Towards midnight, before the wind changed to south-east, it did blow in gusts. In the year 1872 carriages were upset by the wind, whereas in November last they were seen night and day up and down the beach road. In the gale that we had in the latter part of 1874 the wind was stronger and the surf higher than what they were in rough weather under reference.

Note by COLONEL R. H. SANKEY, R.E., Chief Engineer, P. W. D., Madras, on the foregoing letters and concerning the intensity of the storm of 1881,—dated 17th April 1882.

In the accompanying letter from the Master Attendant, No. 2682, dated 4th April 1882, that officer submits his own evidence and that of several experienced marine officers and boatmen as to the character of seas during the cyclone of the 12th November 1881, when the Harbour works were so much damaged.

2. There has been much difference of opinion in regard to the point dealt with in these papers, and as neither the records of past cyclones, nor the evidence available from that of the 12th of last November, afford any very reliable scientific basis for instituting a comparison as to the actual height of the waves, we can only take for what they are worth the opinions of the best qualified observers.

3. Mr. Parkes, in paragraph 8 of his report of the 9th March 1882, observes that "the testimony of all observers is to the effect that the sea of the 12th November must rank with those of the great historical cyclones;" but while adducing the opinion of Mr. Chisholm, the Government Architect, to this effect, he admits that the officers of the Marine Department considered the storm of 1872 to have been the most severe.

4. The undersigned in dealing with this portion of Mr. Parkes' reports—see paragraph 10 of his Note of the 13th March 1882—felt himself compelled to observe that, although "doubtless the seas were much heavier than might have been expected from the comparatively low recorded wind pressure at Madras, as also from other phenomena connected with the storm, many high authorities would be unprepared to accept the cyclone of the 12th November" as affording "a sufficiently crucial test of the forces which may be expected to be called into action in a cyclone of maximum intensity."

5. The evidence now adduced, particularly that by the Deputy Master Attendant, goes far, it is thought, to confirm this opinion.

6. The statement from a note kept by him of the cyclone of 1872, that "as far as the eye could reach between the lulls, the sea out to 9 fathoms of water was a roaring mass of breakers," accurately corresponds with the recollection of the undersigned in regard to one of the cyclones which, late in 1856, burst on Madras, and which he personally witnessed. Viewed from the

top of a two-storeyed house at Ennore the seas were observed to break with the character of a surf right out to sea to an immense distance from the shore.

7. Although not so favourably placed for commanding an equally extensive view in the last storm, he can safely say that no such violent action of the sea was apparent.

8. Since the time when half the French fleet went down off Madras in the storm of October 1746, and so many English store-ships and transports were driven ashore off Pondicherry on the 1st January 1761, down to the cyclone of 1872, the record of all severe storms along the Coromandel coast shows that a great majority of even the best-found ships have foundered at their moorings or have parted their anchors and been driven ashore.

9. Here, however, during the late cyclone the only vessel lying off the port, *viz.*, the barque *Mars*, after riding out the storm till the evening of the 12th November, put to sea as now shown "without difficulty, under an amount of canvas which would have insured her capsizing had she attempted to do so in the cyclone of 1872."

10. The Deputy Master Attendant emphatically says, "The barque *Mars* would have been inevitably lost instead of being enabled to go to sea in ballast trim under double-reefed topsails and reefed foresail." He avers, moreover, that "no such sea prevailed on the 12th November last," as he had previously observed in the cyclone of May 1872. The Pier Master also observes that he saw the "titans fall at a time the sea was nothing to speak of to what it usually is during rough weather."

11. The evidence deduced from the fact of the timber flooring of the screw pile pier (17½ feet above mean sea-level) having been injured in both the storms immediately in comparison is apparently of little value, as during the last occurrence the sea inside the harbour assumed a pyramidal form owing, as stated by the Deputy Master Attendant, to the great volumes of water which were brought in by the wind and sea through the eastern entrance, &c., thus creating a turmoil totally different from the steady normal advance of successive waves with their crests parallel to the coast line.

12. The statements of the native boatmen, who have necessarily such an extensive and intimate knowledge in matters of this character, confirm the opinions expressed by the Master Attendant and his officers.

13. The undersigned would not have dwelt at any length on the evidence now produced had it not been that Mr. Parkes has based his restoration scheme almost wholly on the effects of the late cyclone as, in his opinion, having been one of maximum intensity, or, to use his own expression, "one of those great historical cyclones," whereas the facts, as vouched for by the officers of the department best capable of judging, appears to point to a very different conclusion. Considering the importance thus attaching to the point, he ventures to think that evidence now brought forward should be forwarded to the Government of India and the Secretary of State in continuation of previous correspondence.

From W. PARKES, Esq., M.Inst. C.E., to the Under-Secretary of State for India, on the subject of the intensity of the storm,—dated 2nd June 1882.

I have received through the Superintendent of the Harbour Works an order of the Government of Madras, No. 1008W., forwarding certain papers "to the Government of India and the Secretary of State in continuation of the papers recorded with G. O. No. 780W., dated 23rd March 1882."

2. I think it my duty to call your attention at once to one of these papers, because it contains a statement which is, no doubt unintentionally, quite untrue, and calculated to prejudice the conclusions which I have submitted to the Government. I do not propose to enter at present into any question of *opinion*, but simply confine myself to one of *fact*.

3. The papers consist of a letter from Captain Taylor, the Master-Attendant to the Government, forwarding, with some remarks, the opinions of three officers of his Department and of several other persons as to the relative force of sea in the great storm of May 1872 and in November 1881, and a note thereon by the Chief Engineer of the Presidency.

4. This evidence, interesting and valuable as it is, adds nothing material to the information furnished to me at the Master-Attendant's office before I made my report. Other equally confident evidence to the contrary effect was then before me, and on a review of the whole I felt that I was not justified in saying more upon the comparison of the two storms than that there was a conflict of evidence as to which was attended by the heavier sea.

5. I was bound, however, to follow the course indicated by actual results in my investigations. Having ascertained the weak places in the work, I proposed to apply additional strength to those places, and that to an extent considerably beyond what was actually proved to be necessary by the results of the late storm; this additional security being avowedly intended to meet the possible attacks of still heavier seas.

6. This was in my mind, and it will be seen that I have given occasional expression to it throughout the preparation of my report, and it was therefore with some surprise that I read in the note by the Chief Engineer (paragraph 13) the statement that the late cyclone was "in his (Mr. Parkes') opinion" "one of maximum intensity," and that my restoration scheme was based on this assumption.

7. It is possible that Colonel Sankey's misapprehension may have arisen from the fact that I made observed results the starting points for my recommendations, and abstained from adopting any conjectures as to what heavier seas might do in other directions than those indicated on this occasion. To do so would, in my opinion, be impracticable and unscientific. I look upon the construction of the Madras piers as an important experiment in engineering, of which the results are not confined to mere local benefits, and I should deplore on more than personal grounds a decision of the Government which would throw away the results of the late most important and interesting lesson.

8. I would respectfully ask that the substance of this letter be communicated to the Governments of India and Madras.

Note by Colonel Sankey, R.E., Chief Engineer, P. W. Dept., Govt. of Madras, on the above letter,—dated 26th June 1882.

By the last home mail Mr. Parkes has communicated copy of the annexed letter dated the 2nd June 1882, addressed to the Under-Secretary of State for India, in which he takes exception to the interpretation I had placed on his estimate of the storm of the 12th November 1881, as expressed in paragraph 13 of my note printed with G. O., 24th April 1882, No. 1008W., *viz.*, that it was one of "maximum intensity."

2. The quotation given by me in the paragraph adverted to was taken from paragraph 8 of Mr. Parkes' report of the 9th March 1882, which runs as follows:—

> "The testimony of all observers is to the effect that the sea of the 12th November must rank with those of the great historical cyclones, though there is a conflict of evidence as to whether it was actually as heavy or "heavier;" and then he goes on to quote his authority, Mr. Chisholm, who, he says, "speaks confidently as to the recent sea being considerably heavier than that of 1872."

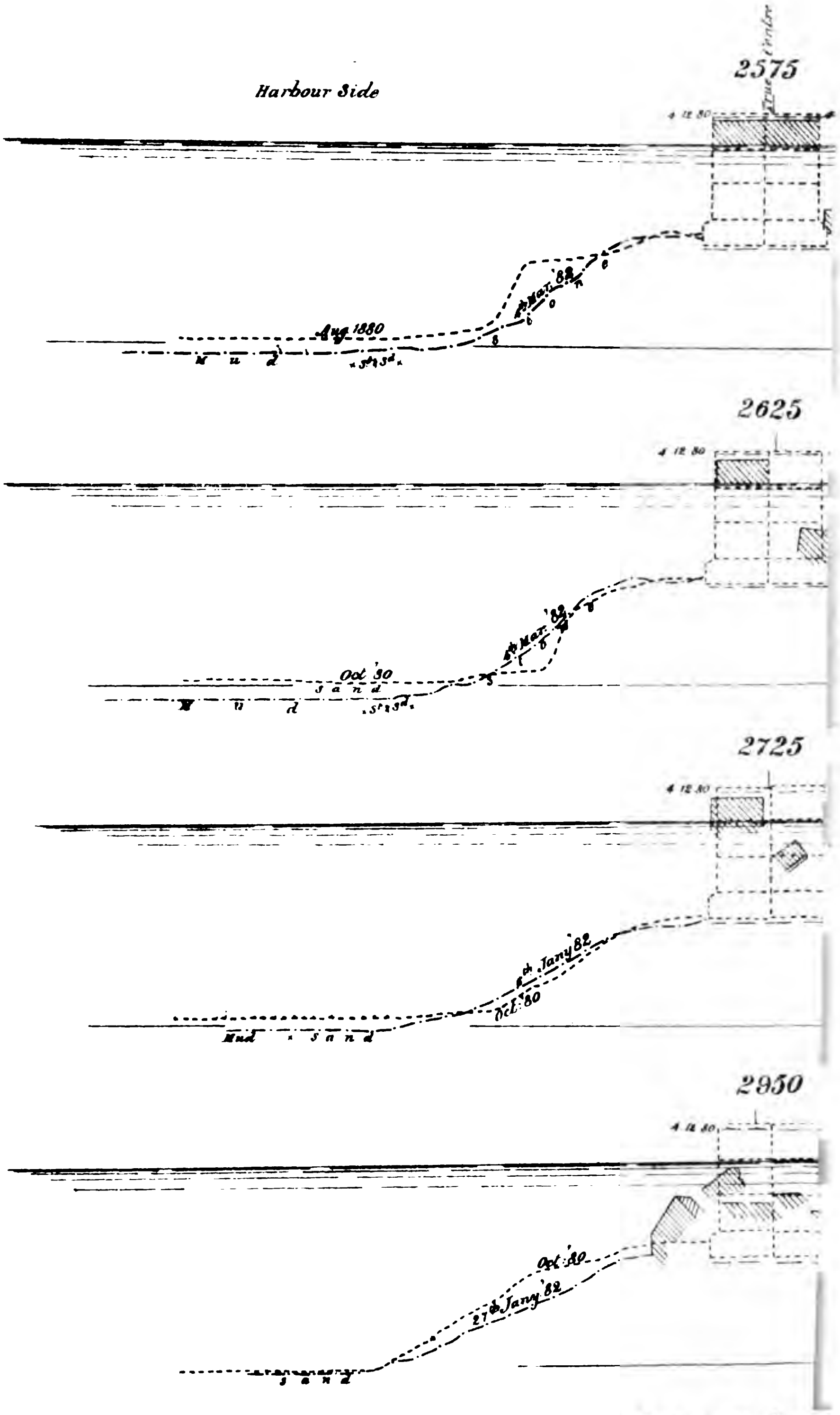
3. My remark that he had based his restoration scheme almost wholly on the effects of the late cyclone, as in his opinion having been one of maximum intensity is, he observes, "unintentionally, no doubt, quite untrue." He is of course the best exponent of his own language, but I submit that I had somewhat strong grounds, as shown by the above quotations, for the conclusion I had arived at. He now contends (paragraph 4) that the evidence furnished by the Master Attendant and other very experienced Marine officers "adds nothing material to what he had himself collected before making his report; but in this case I think it may fairly be inquired why, with the evidence of the professional Marine Department open to him, he set this aside and only quoted that of the Consulting Architect, whose opinion, however valuable in matters connected with his own profession, must necessarily weigh but very little in a case of this kind, even had his opportunities for arriving at an opinion been exceptionally good, which would seem not to have been the case.

4. Mr. Parkes, in paragraph 7 of his present letter, observes that it would have been "impractical and unscientific," had he not made observed results the starting point of his recommendations, and abstained from adopting any conjectures as to what heavier seas might do with his work, and (paragraph 5) that, having ascertained the weak places in the work, he proposed to apply additional strength to those places, "to an extent considerably beyond what was actually proved to be necessary by the results of the late storm," &c.

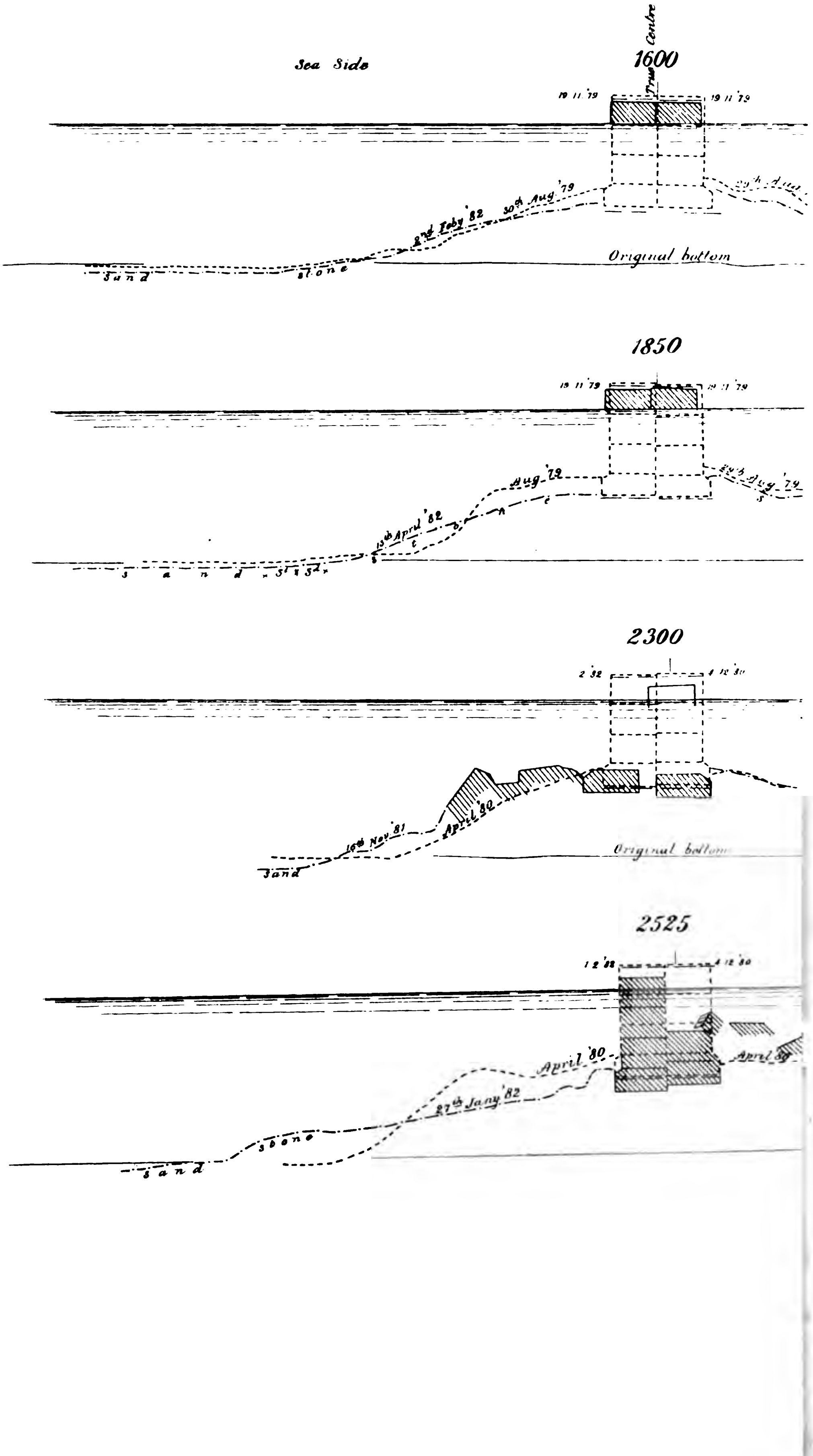
5. Now the sections given of Mr. Parkes' proposed restoration show (paragraph 30 of his report of the 9th March 1882) that the upper part of the completed work will have a thickness of only *three* concrete blocks, but, as noticed by me in paragraph 14 of my note of the 13th March, the piers at their ends where the thickness was *four* blocks had, as a fact, fared no better than where there were only *two*; they had been equally knocked over in the 12th November storm. It is quite true that Mr. Parkes provides an iron cramp between his two front blocks, and also increases the weight of his rear block, but with all this I think it may fairly be questioned whether with these additions his section will be stronger than what it was at the end of the piers in the work which failed.

6. The principle, moreover, of only providing for meeting the shock of a storm which, as it now seems, Mr. Parkes does not consider to have been of "maximum intensity," seems to me wrong.

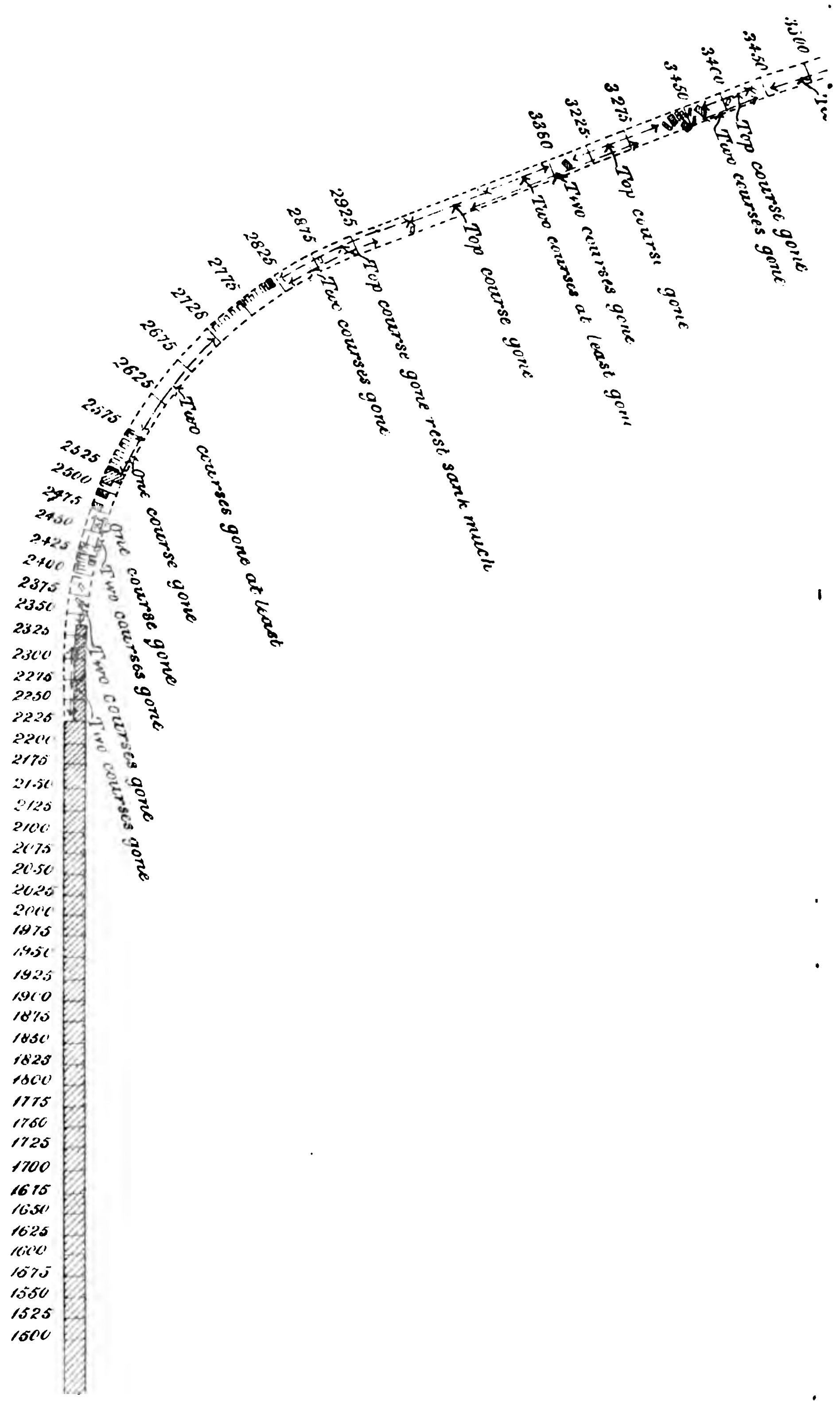
7. It is the duty of the Engineer invariably to provide a sufficiently large margin, to ensure the safety of his work, and this is one of the chief points in which I cannot help thinking Mr. Parkes' design distinctly fails. As his wall should be constructed with the express object of withstanding intact the shock of the heaviest seas and breaking them up, he is bound, I consider, to allow a sufficient co-efficient of safety. He has not, I think, done this,



NOTE _ The sections are at distances as shown
commencement of the Concrete Block P
the left hand side is the Harbour Side i
The Pier indicated by short dotted l
sections of the Base, also indicated by s
the Titan and Engines had passed ove
latest known levels of the Pier before th
The position of the Centre Line is a



Sea Side
True Centre
1600
19 11 '79
19 11 '79
2nd Feby '82
30th Aug '79
Original bottom
Sand
stone
1850
19 11 '79
Aug '79
15th April '82
2300
16th Nov '81
April '80
Original bottom
Sand
2525
April '80
27th Jany '82
April '80
sand
stone



Top course gone
Two courses gone
Top course gone
Two courses gone
Two courses at least gone
Top course gone
Top course gone rest sank much
Two courses gone
Two courses gone at least
One course gone
One course gone
Two courses gone
Two courses gone
Two courses gone

and it is to my mind far from re-assuring to find, at the present stage of this great work, that Mr. Parkes is obliged to look on it as only an "important experiment in engineering."

8. It being of the greatest importance that this subject should be ventilated as much as possible, I take this opportunity to add the following remarks from a letter addressed by the late Captain C. Biden, Master Attendant, to the Secretary, Military Board, dated Madras, 18th June 1851 :—

* * * * * *

"*Para. 16.*—As a remarkable effect of the great force and power of the ground-swell in this roadstead, I may call the Board's attention to the following occurrence, as published in the Asiatic Annual Register for 1808, pages 128—29, to which I myself was an eye-witness, as I was living in quarters on the north beach during the whole of one of the most violent hurricanes that ever assailed Madras, *viz.*, on the 11th December 1807 :—'The sea rose much beyond its usual height, the surf reached Messrs. Harrington's on the beach, and by its violence exposed 4 feet of the foundation of the house; one side of the adjacent building, the Naval Office (where I was residing), is much damaged, the Company's rice godowns were forced open, and much of their contents washed away. The sea rose close to the ditch of the fort and the surf dashed with violence over the ramparts. The counterscarp at the north-east angle gave way, and the water poured into the ditch at every rising of the surf. The bastion at the northern extremity of the Black Town wall gave way, and two guns were dismounted into the sea, &c. Some idea may be formed of the strength of the current and force of the surf from the circumstance of a large portion of the ribs of a ship, supposed to be the *Fairlie*, which was burnt in the roads in 1799, were thrown ashore close to Mr. Parry's godowns.'

"17. This is the remarkable fact to which I have alluded; the wreck thrown aground by the upheaving of the sea was the entire bottom of a ship of about 800 tons burthen with iron kentledge on her floor, and I well recollect that many persons conjectured it was the remains of the *Malabar* burnt and sunk in six fathoms water in 1801, especially her Commander, Captain Kent, who happened to be at Madras during the gale. However, this remarkable instance of so large and weighty a body of wreck being hove high and dry on shore should be taken into consideration when any great outwork for the improvement of the port is in contemplation, and it is very evident that no other barrier than a well-constructed break-water could resist or oppose so tremendous a force."

* * * * * *

From N. St. B. Beardmore, Esq., C.E., Acting Superintendent, Madras Harbour Works, to the Secretary to Government, Public Works Department, concerning sections of the piers of the Madras Harbour after the storm,—dated Madras, 15th July 1882, No. 22 W.

Referring to the note to paragraph 4 of Mr. Parkes' report on the Madras Harbour, of 9th March 1882, I have the honour to forward you a plan and five sheets of sections of the injured portions of the two piers. The five sheets of sections consist of one sheet of each of the curves, one each of the outer straight portions of the piers, and one of the outer part of the inner straight portions of the north pier, showing the scour on the north side in the rubble base, which has now been filled up. Much difficulty was experienced in making this survey, the greater part of it having been made from catamarans; and the fair weather period of the last north-east monsoon was unusually short, or I should have completed a larger number of sections. The intention is to take a section at every 25 feet in the length of the pier, but there will hardly be a chance of taking more until next September or October. If the weather should not be fair enough, then there will be no further chance until February next.

Note by Colonel Sankey, Chief Engineer, P. W. Dept., Govt. of Madras, on the plan and sections forwarded in above,—dated 26th July 1882.

The sections of the ruined piers of the Madras Harbour now received from the Officiating Superintendent, Mr. Beardmore, have apparently been very carefully taken at 50 feet apart along the work, and embrace the following lengths of each, commencing from the outer ends at the Harbour mouth, *viz* :—

	From	To	Total length Sectioned.
North pier	3,850′	1,500′	2,350′
South pier	3,950′	2,400′	1,550′
Total length sectioned .			3,900′

T 1

It will thus be seen that, although about 1,000 feet of the shore end of the south pier (*i.e.* between 2,400 and 1,400 feet) remain to be sectioned, and double the present number to be taken over all, as it is proposed to have sections at every 25 feet, it may be thought that those now submitted will admit of some useful conclusions being drawn.

2. Hitherto the Government have only had before it Mr. Thorowgood's original report, made immediately after the cyclone of the 12th November 1881, and Mr. Parkes's more detailed one, dated 9th March 1882, as indicating the position of the blocks.

3. In paragraph 20 of the letter Mr. Parkes gives what he terms "a typical section of very much of the work in its present state," adding "parts of it are necessarily hypothetical, but there is enough which is matter of actual observation to justify the assumption of the remainder. For a length of at least two-thirds of the damaged parts, blocks 1 and 3 have been traced by the divers and found with slight exceptions to be undisturbed;" and further on: "There is, however, sufficient evidence, direct and indirect, to negative the very improbable supposition of these (the inner lower blocks Nos. 2 and 4) having been undermined and thus caused the fall of the inner wall towards the harbour."

4. As an exception to this generalisation, which affects 1,200 feet of the north and 900 feet of the south pier, Mr. Parkes goes on to show that 400 feet of the first and 500 feet of the second have been differently affected, and in these that probably both the lower blocks Nos. 1 and 2 have been slightly displaced, No. 1 being drawn away a little seawards and tilted.

5. On the positions of the lower blocks as thus determined Mr. Parkes has based his reconstruction scheme on the monolithic system. It is unnecessary at this moment to make any very detailed analysis of the sections as now submitted by Mr. Beardmore, the more so as the further sections promised later in the year will doubtless give the best continuous record which it is possible to obtain; but one can hardly examine those now furnished without being struck by the very much greater displacement of all the blocks, along both the seaward arms of the work, than one would be led to expect from Mr. Parkes' report.

6. It is true there was, later in the year, rather a heavy sea, but Mr. Beardmore has distinctly reported that this occasioned no further displacement of the blocks.

7. Along the south pier, with the exception of the sections taken severally at 3,800, 3,775, 3,750, and 3,725 feet, the disturbance of all the blocks seems very great. Everywhere the piers seem to have shifted towards the Harbour and sunk with a tilt in that direction, showing that where the two lower blocks Nos. 1 and 2 are not actually displaced they have no longer a horizontal bed as indicated by Mr. Parkes's section.

8. Along the north pier the evidence of disturbance is even greater. The sections taken at 3,850, 3,775, and 3,350 feet, alone seem to hold out a hope that the lower blocks are sufficiently unmoved to build upon again.

9. Everywhere there has been great settlement of the work on a whole, and dragging seaward of the rubble base, coupled with other evidence confirmatory of Mr. Molesworth's opinion that the random block system of reconstruction seems the only safe one now to resort to.

10. However this may be, there would seem to be sufficient evidence in the sections now submitted to warrant delay in adopting Mr. Parkes's monolithic system of reconstruction till they have come under the notice of the home experts, who no doubt will be consulted by the Secretary of State.

Despatch by Her Majesty's Secretary of State for India, to the Government of India, regarding the proposed reconstruction of the Madras Harbour Works,—No. 16 P. W., dated 8th March 1883.

I have to inform your Excellency that the Committee* which was appointed in July last to enquire into the present condition of the Madras Harbour, and to report on the measures which should be taken for restoring the works, so as to give reasonable expectation of their future stability, have brought their deliberations to a close, and have submitted a report,† copy of which I now forward, for the information and guidance of your Government.

* Sir John Hawkshaw, F.R.S.
Sir John Coode.
Professor Stokes.

† Dated 23rd January 1883.

2. Mr. Parkes, the Chief Engineer of the Harbour Works, has been in frequent communication with the Committee in their investigations, and has had an opportunity of seeing their report. The letter‡ enclosed herewith will show your Excellency that he concurs in the general principles on which the Committee recommend that the work of restoration should proceed, but considers that in certain particulars modifications may be desirable. You will observe, also, that he is of opinion that four years will be required for the completion of the works contemplated.

‡ Dated 10th February 1883.

3. The estimated cost of reconstructing the harbour, in accordance with the proposals of the Committee, is £480,000. This may be susceptible of reduction, but is in excess of estimates hitherto made.

4. After careful consideration of the whole subject, I have come to the conclusion that, so far as the engineering questions involved are concerned, the views expressed in the report of the Committee consulted under Lord Hartington's instructions, consisting, as that body did, of authorities eminently qualified to advise on the very difficult problem to be solved, should be accepted as closing the discussion on the principle of restoration to be followed, if the decision be come to that the additional outlay which is requisite should be incurred. There is nothing in Mr. Parkes's letter to lead to hesitation in this respect, and I understand that the Committee are of opinion that the work of restoration might be set about with every reasonable expectation that the structure could be satisfactorily completed and maintained on the proposed design.

5. While I am of opinion that the reconstruction of the harbour should be undertaken at the estimated cost, before coming to a final decision to incur so large an outlay, I desire to be informed of the views of your Excellency's Government on the financial aspect of the question. On receipt of your reports, I shall reconsider the whole subject, and my decision will be communicated to your Excellency with the least possible delay, any needful instructions being also then given to Mr. Parkes for his future guidance.

6. I have furnished a copy of this Despatch and of its enclosures to the Government of Madras, with whom you will no doubt deem it desirable to place yourself in communication at an early date.

Report by Sir John Hawkshaw, Sir John Coode, and Professor G. I. Stokes, on the measures which should be taken for restoring the works of the Madras Harbour,—dated London, 23rd January 1883.

On the 8th July last, we had the honour to receive a communication from Lord Enfield referring to serious damage to the works of the Madras Harbour by a severe cyclone which had occurred in the preceding autumn, and informing us that certain proposals having been made for restoring the works, the Secretary of State for India was desirous that the subject should be investigated by competent professional authorities in this country, and that Lord Hartington had decided to appoint a Committee for the purpose, and proposed that we should constitute that Committee.

Lord Enfield's letter is given in the Appendix, and having consented to act under its instructions and provisions, we have now to report our proceedings, and the conclusions at which we have arrived.

The following documents have been forwarded to us, and have had our consideration, *viz.*—

Report by Guilford L. Molesworth, Consulting Engineer to the Government of India for State Railways, to the Secretary of the Government of India, Public Works Department, dated Calcutta, 1st March 1882.

Report by A. W. Stiffe, Port Officer of Calcutta, to the Secretary to the Government of India, Public Works Department, dated Calcutta, 13th March 1882.

Note by Colonel R. H. Sankey, R.E., Chief Engineer of Government of Madras, Public Works Department, Buildings and Roads, Civil Works, dated 23rd March 1882.

Report by William Parkes, Engineer-in-Chief of Madras Harbour Works, to the Secretary to the Government of Madras, Public Works Department, dated Madras, 9th March 1882.

Note by Colonel R. H. Sankey, R.E., referring to, and accompanied by, sections of Pier, dated 26th July 1882, and by an extract from the Proceedings of the Madras Government, Public Works Department.

Government of Madras, Public Works Department. Papers numbered 33, 34, 72, and 73. Remarks on correspondence on the comparison of the storms of 1872 and 1881, by William Parkes.

Letters from D. E. Dalrymple, late Master Attendant, Madras, and Chief of the Marine Department, Madras Presidency, dated July 11th and August 24th, 1882.

In the course of our enquiry we have been in frequent communication with Mr. Parkes, the Engineer-in-Chief of the Harbour Works, who has from time to time supplied us with documents and information explanatory of the state of the works and of his views of methods and cost of restoration. We have also had interviews with Mr. Thorowgood, the Resident Engineer of the Works.

We thought it desirable to request Mr. Dalrymple, to whose letters we have referred, to attend one of our meetings and to afford us such further information as he thought proper on the statements in those letters, and we have had the benefit of his explanations and opinions.

We have also taken advantage of Mr. Guildford Molesworth's visit to England to obtain his views on several matters.

A question raised in the correspondence is whether the cyclonic storm of 1872 or that of 12th November 1881, was the stronger, and on this point the evidence of boatmen and others is adduced, and contradictory statements are made. Mr. Chisholm is of opinion that the waves of the storm of November 1881 were more formidable than those of the storm which passed over Madras in 1872. Lieutenant Taylor expresses an opinion that the attack upon the works by the storm of November 1881 was a mild one. In the absence of accurate means of measurement, there is nothing on which greater diversity of opinion is more likely to arise than on the intensity of storms. It would be useful to know, could any one tell, whether the storm of November 1881 was the most severe the Harbour Works can ever be subjected to, but this is information that cannot be obtained. The facts we have as regards the storm of November 1881 are its effects on the Harbour Works, and though we can have no doubt the storm was a very severe one, it will be safer in considering the question referred to us to assume that neither the storm of 1872 nor that of 1881 was necessarily a maximum one, as the period of nine years within which both occurred is too short an interval to justify such a conclusion.

In all estimates of the intensity of storms, it should be observed that long waves, more of the nature of heavy ground swells, may severely try harbour works, and that such waves are compatible with the absence of strong winds at the place itself and with comparative smoothness in the offing.

The present condition of the piers, and the damage they sustained by the cyclone, have been fully described in the Reports before us. Generally, we may say that, from the shore ends to the commencement of the elbows, the walls are standing, but from the commencement of the elbows outward, they are so far destroyed as to render it necessary to reconstruct them.

In considering proposals for restoring and strengthening the Harbour Works, questions naturally arose whether any portion of the damage done could be attributed to the mode of construction, or whether it arose entirely from the dimensions and mass of the piers being insufficient.

The method adopted of building the piers was to form a rubble mound, on which the walls were built, and though we do not concur in Mr. Parkes's view as to the depths below which wave action in engineering works may be disregarded, for those depths must have relation to the magnitude and character of the waves and the weight and size of the material acted upon, yet, having regard to the magnitude of the seas then contemplated, the walls were founded sufficiently deep below low water, and the general outline of the design was not inappropriate, but there appears to have been difficulty in procuring suitable material for the rubble mound. Mr. Molesworth states that the size of the stones of which the rubble base is composed varies from 5lb to 2cwt., which is small for the purpose, especially where laterite is used, which varies much in quality and is sometimes so soft as to be easily still further reduced in size by the slightest movement.

The superstructure of the piers was not built of one bonded mass, but consisted of two parallel walls placed side by side in juxta-position, having a vertical joint between them; and from the portion of the walls on the harbour side of the piers having in places fallen away from the portion on the outer or sea-side, it seems probable that the pressure of water in the joints led in great measure to this result. The oscillation of the two halves of the wall, also caused by the want of bond and the consequent opening and closing of the vertical joint referred to in Mr. Molesworth's report, must be remedied, as it may in time prove mischievous. No doubt the method of building adopted by Mr. Parkes conduced to rapidity of construction, but were the work to be begun again, we could not recommend this method, but should prefer the work being bonded throughout.

Though of this opinion, we do not wish it to be inferred that the walls if bonded would have proved strong enough to have withstood the storm to which they were exposed. To make the piers secure against severe gales, it will be necessary to add materially to their strength of resistance, and having regard to the magnitude of the waves which roll into Madras roads and overtop the walls, the piers should be raised to a higher level than that hitherto contemplated. They were originally built by Mr. Parkes to an average height of about 6 feet 4 inches above high water-mark before settlement, but we are of opinion they should be raised so that their finished level shall not be less than 12 feet above high water-mark. This will add to the security of vessels within the harbour in rough weather, and will greatly strengthen the work, as we propose the piers should be raised to this extra

height by adding a monolithic capping of concrete in mass which, aided by iron cramps to be inserted in the upper courses of block work, will help to secure and hold together the concrete blocks in the wall beneath, and tend to remedy the want of bond we have before referred to.

The works we recommend, and have had under consideration, will be understood from the accompanying Drawings, Nos. 1 and 2, to which we beg to refer, and which consist of—

A plan of the harbour, Drawing No. I.

Five cross-sections of the piers, numbered respectively 1, 2, 3, 4, and 5, Drawing No. 2.

The portions of the Piers to which the cross-sections apply will be seen by reference to the drawings.

Cross-section No. 1 will be applicable to the shore ends of the piers, from their commencement to the point A in the case of the north pier, and to the point D in the case of the south pier, being a length of 400 feet and 650 feet respectively.

Cross-section No. 2 will be applicable to both piers, *viz.*, from A to B on the north pier, being a length of 1,800 feet, and from D to E on the south pier, being a length of 1,750 feet.

Cross-section No. 3 will be applicable to both piers, *viz.*, from B to C on the north pier, being a length of 1,600 feet, and from E to F on the south pier, being a length of 1,520 feet.

Cross-section No. 4 is an alternative to cross-section No. 3, and would be applicable under the conditions hereafter explained.

Cross-section No. 5 shows a method of reconstruction by adopting random concrete blocks.

For the landward portion of the piers, the works we recommend to be undertaken (shown on Cross-section No. I) consist of cramping each pair of blocks in the upper course, and the addition of a mass of concrete carried up to 12 feet above high-water spring tides, the level to which we consider it necessary to raise the piers throughout their entire length. This mass of concrete and the cramping will prevent the oscillation of the two halves of the wall, and are necessary to remedy the want of bond we have referred to. We have not shown wave-breakers along the landward portion of the piers, but the rubble mounds should be carefully examined, and, where requisite, made good by gneiss rubble of large size, or by concrete blocks.

For the next length of the piers, extending to the elbows, in addition to the cramping and the top mass of concrete, a wave-breaker, shown on Cross-section No. 2, of random concrete blocks, should be added on the seaward face, which will render it necessary to widen the rubble mounds. The concrete blocks for the wave-breakers should nowhere be less in weight than twenty tons.

As respect the piers from the points B on the north pier and E on the south pier to the seaward ends, it would be desirable, if it could be done, to continue the walls on the original foundations, bonding the blocks in the manner shown, strengthening and protecting the walls as they are built by wave-breakers, and depositing bags of concrete at the toe of the wall on the harbour side to form a continuous apron. (See Cross-section No. 3.) But picking up the blocks buried or nearly so in débris, for the purpose of resetting them, or preparing a sufficiently level bed on the site of the destroyed wall, will involve great labour and expense, and possibly even it may be found impracticable to continue the wall on the original foundations.

A more certain plan of procedure for the reconstruction of these outer lengths of the piers would be to move them into the harbour to the extent of about 60 feet, so that the new walls may clear the fallen blocks of the old structure, adopting the design shown on Cross-section No. 4, and this would involve a somewhat less expenditure than building on the original foundations. But it would shorten the harbour—already very short—to the extent of about 60 feet: and also it would be undesirable, if it could be avoided, to build on a new foundation of unconsolidated rubble, instead of taking advantage of the old consolidated mounds.

The plan, therefore, we recommend for the reconstruction of the outer lengths from B on the north pier and E on the south pier, to the seaward ends, is in the first instance to endeavour to continue the walls on the old foundations, as shown on Cross-section No. 3. Before the elbows of the piers are finished it will be seen whether this plan can be successfully carried out; if so, the system should, we think, be followed. If not, the piers should be brought in to the extent of about 60 feet, following the design shown on Cross-section No. 4.

We have carefully considered the question of reconstructing these outer lengths from B on the north pier and E on the south pier to the seaward ends by mounds of random concrete blocks, more especially as the plan has been recommended by others. It possesses advantages, and as regards construction is a safe system to follow. But it would be necessary to build a short length of wall at the extremity of each pier upon which to place the entrance lights, and, owing to the size of the vacuities, amounting to between one-fourth and one-third of the mass, the seas may pass through sufficiently to produce some disturbance inside. If the Madras

Harbour were of larger size, and there were ample space for the waves to disperse, the system would be more applicable; but, the sheltered area being limited, it is important that the whole space should be made as quiescent as possible. We have, however, thought it right to go carefully into the cost of reconstruction by adopting random mounds for these outer lengths, and find that there would, comparatively speaking, be but little saving in expenditure in adopting this mode of procedure, in preference to building walls on the original foundation with a wave-breaker (shown on Cross-section No. 3), as recommended for adoption.

The order of proceeding with the works should be first to secure by iron cramps the top courses of the walls which are now standing, that is to say, from the shore to the commencement of the elbows; to re-instate the walls which have been disturbed or thrown down, carefully cramping the top courses together as the work proceeds, and simultaneously in both cases to proceed with depositing the blocks for the wave-breakers so as to afford early protection to the rubble mound and the walls. Raising the walls by concrete in mass will be the last process, as that portion of the work can only conveniently be done by beginning it at the outer extremities of the walls and working back towards the shore.

For the purpose of arriving at an estimate of the cost of reconstruction, we have assumed the definite lengths previously referred to for the different methods of procedure recommended to be followed and shown on the cross-sections. The details of the estimates are given in the Appendix. We estimate the cost of restoration, strengthening, and raising the piers at £480,000 (see estimate No. 1), assuming that the lengths from B on the north pier and E on the south pier to the seaward ends were reconstructed on the original foundation. If, however, these outer lengths of the walls were brought in 60 feet, the cost, we estimate, would be reduced to £430,000 (see Estimate No. 2). We have also given an estimate of the cost, assuming that these outer lengths were reconstructed by random mounds of concrete blocks (see estimate No. 3).

These sums are large, but, in our opinion, a smaller expenditure will not render the work secure.

Even with this additional expenditure, the cost of the piers, having regard to their length and to the depth of water, will not be excessive.

In comparing our estimate of cost with that prepared by Mr. Parkes, it must be remembered that his did not provide for raising the piers to the height which we think is essential. We have also, in some cases, assumed higher prices than he has done, ours being given in the annexed estimates. If the work can be well and properly executed at lower prices, so much the better.

With the additions to the works which we advise, their strength and durability will still be dependent on the materials and workmanship being of the best quality; for such works, if they are to last, must be thoroughly well done.

Whether from defects in the quality of the concrete or from the blocks being used too soon, or from placing them upon the rubble base before it was sufficiently consolidated, several of the blocks appear to have been broken. No concrete block of such large size ought to be used until at least three months after it has been made, and giving them six months to harden would be still better. The local laterite also does not appear to be of good quality, and hence nothing but gneiss should be used in the additions to the rubble mound.

Suggestions have been made to stop up the present or eastern entrance in front of the harbour, and to make an opening facing southwards in the south pier. This would involve very large additional expenditure, and we cannot recommend it, more especially as we do not think it would be an improvement.

We think the harbour, if completed in accordance with our recommendations, will be useful for shipping, and that raising the piers so as to prevent their submergence by seas rolling over them will, with the present width of entrance, render it quieter than before. But its stillness would be further increased by reducing the width of its entrance from 550 feet to 450 feet, and, as we think this ought to be done, we have included the cost of it in the estimates. The reduction of width might be carried out hereafter, but in that case the cost would be increased.

Mr. Parkes does not appear hitherto to have made provision for lighting the entrance of the harbour. This will be necessary, but we have not sufficient information to propose a plan for or to estimate the expense of doing it.

Copy of Lord Enfield's letter referred to in the above Report—dated India Office, S.W., 8th July 1882.

I am directed to inform you that certain proposals have been made for restoring the work of the Madras Harbour, which were seriously damaged by a severe cyclone last autumn; but

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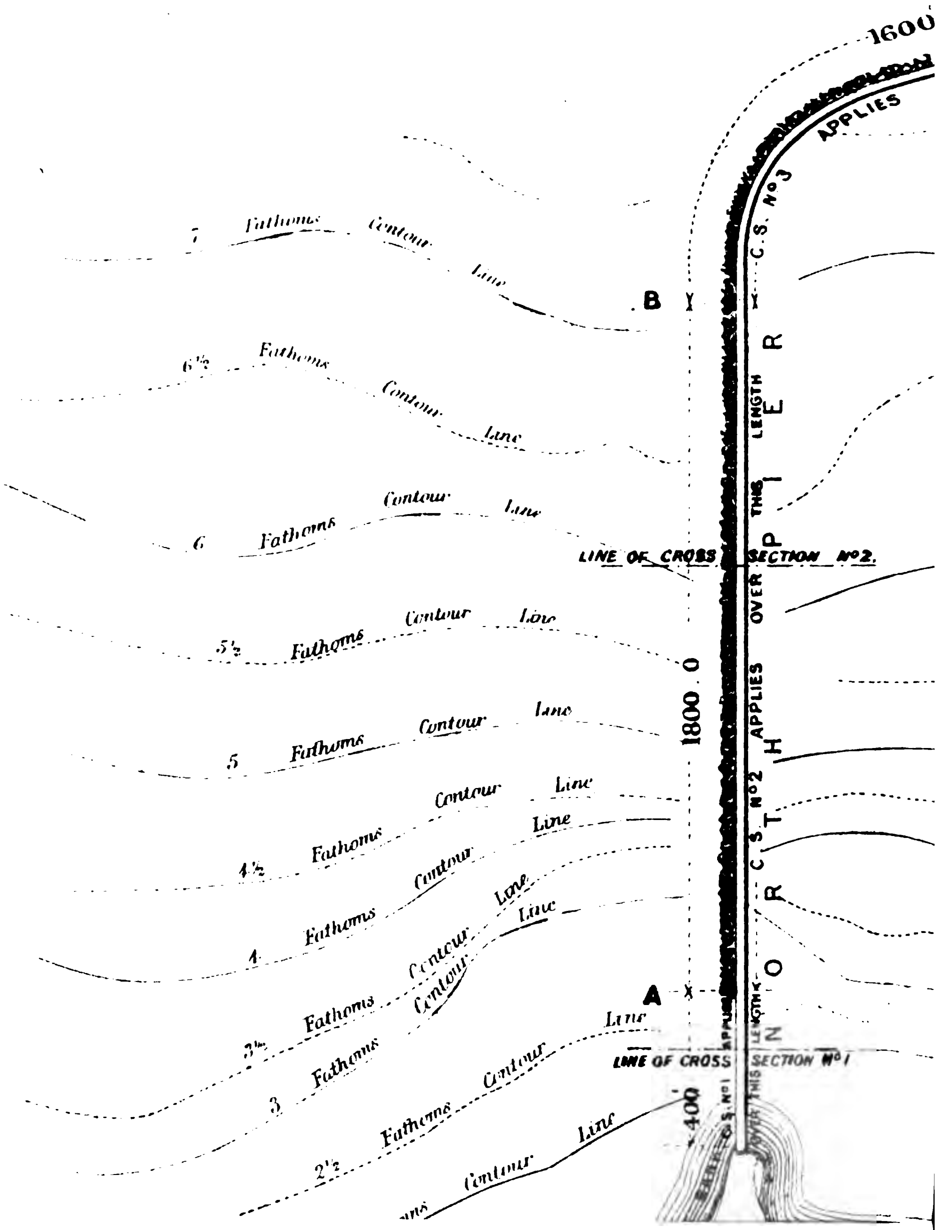
To accom



1600
APPLIES
C.S. No3
B
A
7 Fathoms Contour Line
6½ Fathoms Contour Line
6 Fathoms Contour Line
LINE OF CROSS SECTION No2.
5½ Fathoms Contour Line
5 Fathoms Contour Line
1800.0
4½ Fathoms Contour Line
4 Fathoms Contour Line
3½ Fathoms Contour Line
3 Fathoms Contour Line
LINE OF CROSS SECTION No1
2½ Fathoms Contour Line
400
NORTH PIER
C.S. No2 APPLIES OVER THIS LENGTH
OVER THIS LENGTH

that before deciding upon the measures which should be taken for effecting this object, the Secretary of State for India is desirous that the subject should be investigated by competent professional authorities in this country, in communication with the Engineer-in-Chief of the Works, Mr. Parkes.

Lord Hartington has accordingly decided to appoint a Committee for the purpose; and I am instructed to state that His Lordship will be glad if you will join one composed of yourself, Sir J. Coode, and Professor Stokes.

The papers particularly referred to you consist of a report made by Mr. Parkes, containing a scheme for the restoration of the works, based on a minute personal examination of their present state, together with the independent suggestions of Mr. Molesworth, Consulting Engineer to the Government of India for State Railways, and Lieutenant Stiffe, Port Officer of Calcutta.

Lord Hartington is of opinion that it is desirable to bring the whole matter under reconsideration, with such further light as may be thrown upon it by the independent experience of other engineers, and the most recent investigations and researches into the action of waves.

It will be open to the Committee to take such steps as they may deem fit to enable them to arrive at a definite and conclusive opinion on the subject.

Mr. Parkes himself entirely concurs in this course, and you are therefore requested to put yourself in unreserved communication with him, and to report to this office, in such form as shall appear to be most suitable, your opinion whether the works can be so restored as to give reasonable expectation of their future stability; and if so, what method of construction should be adopted to that end.

I am to add that the precise terms of your professional remuneration will be settled at the close of the investigation.

NOTE.—The above is a copy of the letter sent to Sir John Hawkshaw, but a similar one was sent to Sir John Coode and to Professor Stokes, with the necessary substitution of names.

Estimate No. 1, referred to in the annexed report for the reconstruction of the piers in accordance with Cross-Sections Nos. 1, 2, and 3.

						£	s.	d.
Cubic yds. 266,888	Additional rubble in mounds				5/6	73,394	4	0
88,862	Concrete blockwork in walls of piers				23/-	102,191	6	0
161,678	Concrete blocks in wave-breakers				23/-	185,929	14	0
5,408	Aprons of concrete in bags				23/-	6,219	4	0
40,410	Concrete in mass on the top of the piers				20/-	40,410	0	0
53,733	Removal of old blocks, at 10/-	£26,866	10	0				
	Deduct value of old blocks put into mounds instead of rubble, 53,733 cubic yds., at 5/6	14,776	11	6				
						12,089	18	6
Tons. 171	Wrought-iron cramps				£20	3,420	0	0
No. 2	New setting machines					12,000	0	0
						435,654	6	6
	Establishment (7½) and Contingencies (2½) = 10 per cent.					43,565	8	8
						£479,219	15	2
	Say £480,000.							

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Estimate No. 2, referred to in the annexed report for the reconstruction of the piers in accordance with Cross-Sections Nos. 1, 2, and 4.

			£ s. d.
Cubic yds. 286,177	Additional rubble in mounds	5/6	78,698 13 6
88,862	Concrete blockwork in walls of piers	23/	102,191 6 0
128,051	Concrete blocks in wave-breakers	23/	147,258 13 0
5,408	Aprons of concrete in bags	23/	6,219 4 0
40,410	Concrete in mass on the top of the piers	20/	40,410 0 0
Tons. 171	Wrought-iron cramps	£20	3,420 0 0
No. 2	New setting machines		12,000 0 0
			390,197 16 6
	Establishment (7½) and Contingencies (2½) = 10 per cent.		39,019 15 8
			£429,217 12 2
	Say £430,000.		

Estimate No. 3, referred to in the annexed report, for the reconstruction of the piers, in accordance with Cross-Sections Nos. 1 and 2, Landward of the elbows, and for mounds of random concrete blocks seaward of the elbows.

			£ s. d.
Cubic yds. 353,270	Additional rubble in mounds	5/6	97,149 5 0
26,062	Concrete in mass on the top of the piers	20/	26,062 0 0
242,178	Concrete blocks in mounds and wave-breakers and blockwork heads at extremity of piers	23/	278,504 14 0
7,067	Concrete in bags in the upper part of mounds	23/	8,127 1 0
Tons. 71½	Wrought-iron cramps	£20	1,430 0 0
No. 2	New setting machines		12,000 0 0
			423,273 0 0
	Establishment (7½) and Contingencies (2½) = 10 per cent.		42,327 6 0
			£465,600 6 0
	Say £466,000.		

From W. Parkes, Esq., to the Under-Secretary of State for India, communicating remarks on the foregoing report,—dated the 10th February 1883.

I have the honour to submit the following remarks on the Report of the Committee, consisting of Sir John Hawkshaw, Sir John Coode, and Professor Stokes, in accordance with the request conveyed to me in a reference from Mr. Danvers, dated 5th instant. The Report is returned herewith.

2. It should be understood that, although I was in frequent communication with the Committee during the progress of their investigations, and furnished them with all information in my power as to matters of fact, and as to my own views, both orally and in writing, and also conveyed to them several documents forwarded to me for that purpose by the India Office, the conclusions given in their Report were arrived at quite independently of me. I was informed of their general character in December, and the plans attached to the report were shown to me on the 19th January, but I did not see the report itself till it was forwarded to me on the 5th instant, as above.

3. I have thought it desirable to mention these facts in order that my own share in the investigation may not be misunderstood. While admitting that the course adopted by the Committee has its advantages, and at the same time trusting that the Report may serve the purpose intended by the Government, I would submit that, in considering their conclusions, and taking action upon them, a large allowance must be made for the fact that the gentlemen composing the Committee are not personally acquainted with the locality, and that their local information was obtained at second-hand.

4. This consideration will not affect the main features of their recommendation, but it does materially affect the position of the line of demarcation between fixed principles and details which may be subject to modification in respect of their relation to local circumstances. The details of their plan should be viewed, I would submit, rather as illustrations of the general meaning of the authors, or at most as a basis for approximate estimate, than as a basis for instructions to the engineer who will be charged with the execution of the works.

5. Subject, then, to the limitations implied in the above remarks, I may state that I have, after full consideration, come to the conclusion to acquiesce in the general recommendation of the Committee that the additional strength required should be given by a large wave-breaker, consisting of concrete blocks laid at random on the sea-face. I need not say that I have come to this conclusion with great reluctance, because it involves a very large additional outlay, which would have been saved if the more inexpensive plan which I proposed in March last had met with independent professional support. I do not think, however, that I should be justified in urging the latter further, even if my present opinion, that it would have possessed the necessary elements of stability, should remain unchanged, for I think this to be essentially one of those cases in which action should be taken only with a strong concurrence of professional opinion. It is a matter upon which there is no very direct experience to guide us, and the theoretical considerations applicable to the case are involved in some doubt. Moreover, it might be many years before the stability of the work would be brought to a satisfactory test, so that whatever there might be doubtful in the question would remain unsolved for an indefinite time.

6. I have been of opinion from the first that the system of random blocks is the only alternative to my original proposal, and I think that the dimensions of the mound suggested by the Committee are the least that ought to be adopted for the most exposed parts of the piers. These dimensions are considerably greater than those which were offered as an alternative to my proposals from two or three quarters a year ago, and which I always felt to be insufficient, though I was unwilling, without more data than were accessible to me while in India, to attempt to form any definite conclusions as to what was really adequate. Since my return to England in May last I have given much attention to the subject, and my conclusions, based on information derived from many quarters, are very similar to those at which the Committee have independently arrived.

7. So far, therefore, I am entirely in accord with the Committee, and as far as it is possible to dissociate general principles from their application to a particular case, our accord, I believe, goes much further. But for the present this is as far as I feel justified in following the actual lines laid down by the Committee, though with so much common ground for our departure, it is hardly likely that there would be any very great divergence in the further development of our views.

8. The adoption of the random mound system instead of the built additions I proposed for the 1,000 yards most seriously damaged involves, in round numbers, an additional expenditure of 15 lakhs of rupees to the 18 lakhs of my original estimate. The continuation of the same system shorewards, with gradually decreasing dimensions, would involve a still further excess of outlay, so that the large estimates given by the Committee would probably be approached by any that I could myself frame upon a design based on the ground common to the Committee and myself.

9. I may therefore suggest, as a safe assumption, that the amounts estimated by the Committee should be taken as the data for the consideration of the financial view of the question.

10. It may be assumed, however, that the sum of 480,000*l.*, the estimate for the scheme specially recommended, is equivalent to 48 lakhs of rupees, and that it may also be taken as a *maximum*, subject to probable diminution. I find that the rates upon which this estimate is based are slightly in excess of those upon which the work has been hitherto carried out. I furnished these latter to the Committee, and they appear to have converted them into sterling money at the rate of 2*s.* to a rupee, and then made the slight additions. This excess is, I believe, an allowance to cover the cost of additional plant—an allowance which I am in the habit of making as a separate item. Assuming therefore the quantities given in the estimate, I can confirm the total amount. Credit, however, should be taken for the value of materials now on the ground, and available for future use (including concrete blocks prepared for the ends of the piers which were unfinished at the time of the storm). This amounts to about one lakh. It should also be borne in mind that the estimate is swelled by the cost of the additional 100 feet of pier recommended to narrow the entrance from 550 to 450 feet. This would be in round numbers 1½ lakh.

11. It is also clear that the committee have adopted the most unfavourable assumption possible of the extent to which the blocks in the damaged parts of the work will be available for further use. This is perhaps the safest course for the present; but it should be understood that there is a certainty of some saving in this respect, though its amount is indeterminable till the blocks are actually recovered. I think if the *least* instead of the *most* unfavourable view were taken on this point, there would be a saving of seven or eight lakhs of rupees. A recent examination, made under exceptionally favourable circumstances, confirms the best expectations previously entertained upon this point. On all these grounds, therefore, I think I am justified in asking that the 48 lakhs should be taken as a *maximum*.

12. The Committee put forward two alternative schemes, which are both estimated as somewhat less costly than the one they recommend. It is perhaps desirable to show what there is to fall back upon in the event of any very unforeseen difficultiesi n carrying out the more favoured plan, but I think the arguments adduced by the Committee against these alternatives may be strengthened by other considerations. Both were fully considered on the spot during my investigations last year, and both rejected, not as absolutely impracticable, but as unsuitable in many respects. I believe also the apparent economy in comparison with the recommended plan would vanish on further investigation.

13. I would beg to offer some remarks on two points raised by the Committee at the end of their report, *viz.*, narrowing the entrance, and lighting it. They estimate for the former, but not for the latter, stating, however, with regard to the latter, that provision will have to be made for it.

14. With regard to the entrance, it is satisfactory to find that the Committee confirm the propriety of its present position as a question of general design. As to the special nautical considerations on which a change has been advocated, no evidence, except that contained in the papers, was brought before them, and as that is all on one side, their conclusions adverse to a change is based entirely on general grounds. I am bound to say that, if an immediate decision were necessary, I should agree with the Committee; but considering that no measures can be taken to carry out either the narrowing or the entire change of position till all the other works are completed, I would submit that it is undesirable, in view of the strong opinions expressed by the Marine authorities, to come to any decision at present. The eastern entrance, 550 feet wide, exists, bad or good, and must be used for the next four or five years. During that time it will have a more extended trial than it has yet had, and there will be more material for a final judgment. I would express a hope therefore that no definite order be given, either for reducing the width, or for altering or retaining its position, until nearer the time for carrying out the actual work. It need not be concluded, however, that the efficiency of the harbour is dependent upon the width or position of the entrance. Even admitting that a change in either respect would be an improvement, it will not make the difference between a harbour and no harbour; it would only give more accommodation, which, of course, if required, would bring more revenue.

15. With regard to lighting the entrance, the matter has had much consideration, and though I cannot say that a definite plan has been decided upon between the Marine officers and myself for submission to Government, I am satisfied that no very costly works will be required. The sum of R 20,000 stands in the amended estimate last sanctioned for this purpose, and this amount will be ample for anything I can contemplate. I do not think it would be desirable to facilitate the entrance of ships in very bad weather at night. They should stand out to sea, or anchor in the roads till daylight. The position of the inner limits of the anchorage might be marked by intersecting shore lights, though the soundings give an excellent indication of a ship's position. In fine weather, however, the entrance should be marked either by

leading lights on shore, or by small lights on the pier heads, which latter should not be exhibited at all in bad weather. I think these arrangements would meet all the requirements of the trade as at present conducted, and it is therefore unnecessary to contemplate any provision for lighting beyond the already sanctioned amount.

16. I think, considering the great addition to the quantity of work involved in the adoption of the wave-breaker system, at least four years would be required for the completion of the works, reckoned from the time of recommencing block setting. This could not be done in less than nine or ten months from the issue of the Government sanction, as the titan cranes will have to be manufactured in this country, sent out, and re-erected on the spot.

Extract paras. 1 to 8 of a letter from COLONEL R. H. SANKEY, C.B., R.E., Secretary to the Government of Madras, P. W. Dept., to the Secretary to the Government of India, P. W. Dept., forwarding report of the Committee appointed to consider the best means for restoring the works of the Madras Harbour,—No. 1856 W., dated 4th July 1883.

With reference to Despatch No. 10, Public Works, dated 8th March 1883, from the Right Honorable the Secretary of State, on which this Government was desired to consider the recommendations of Sir John Hawkshaw's Committee on the Madras Harbour, dated 23rd January 1883, " in view to assisting the Government of India to arrive at a decision upon the course which it will be most desirable to follow in reference to the work of restoration," I am now directed by His Excellency the Governor in Council to submit the annexed report of a Committee which was lately assembled at Madras to frame the needful estimates, and to consider the question of restoration in all its bearings.

2. In the first place, as regards the estimated cost of the works, this Committee, on a close review of the rates of work, time required for execution, &c., find that to restore the break-waters on the plan most favoured by Sir John Hawkshaw's Committee (*i.e.*, as per Sections Nos. 1, 2, and 3 of their report) would be as follows, *viz.*—

	R
(1) While retaining the present harbour entrance	50,93,980
(2) While reducing the entrance to 450 feet	51,85,580

The latter sum compares directly with the Home Committee's Estimate No. 1, amounting to £479,219-15-2.

3. As will be observed, the Madras Committee have shown by the highest nautical opinion that it would be dangerous to decrease in any way the width of the present eastern entrance, and that so long as this latter is left open, the harbour must remain exposed, as at present, to continued disturbance, as well as being a perpetual source of the gravest anxiety to all concerned during cyclone periods.

4. They further show that, while carrying out for the seaward arms the random block method of reconstruction, which is stated to be " a safe system to follow " by Sir John Hawkshaw's Committee, the objectionable eastern entrance may be closed, and a perfectly still-water harbour created, at a total outlay of R 51,42,626, or for R 42,954 less than that needed for reconstructing the works in the manner most approved by the Home Committee.

5. The incidental advantages of the plan suggested (see paragraphs 46 to 54 of the present Committee's Report) are so marked that His Excellency in Council trusts that they may be fully weighed in arriving at a conclusion in regard to the completion of this great work.

6. Not only would the Harbour enjoy complete immunity from disturbance during ordinary weather, thus facilitating in every way all the trade operations of the port, but, what is of the highest moment, no ships need be sent to sea on the commencement of a storm. It is impossible, in the opinion of this Government, to lay too great a stress on this single fact, or to doubt the soundness of the reasoning on which it has been established.

7. Not only, moreover, could the harbour, under the altered conditions, be dredged out and its area increased to any required extent, but, as observed by the Committee, it might, by a suitable system of defences, form a complete harbour of refuge in times of war.

8. As regards the resumption of the works, I am now to submit that every day's delay is adding to the cost of establishment, and continues the disadvantages under which the trade of the port has been suffering since the cyclone of the 12th November 1881.

Orders of the Govt. of Madras, P. W. Dept., concerning the committee referred to above,—No. 1259 W, dated 30th April 1883.

In order to give effect to the instructions conveyed by Her Majesty's Secretary of State in paragraph 2 of Public Works Despatch No. 10, dated 8th March 1883, that this Government

should take into consideration the best means for restoring the works of the Madras Harbour, in view to assisting the Government of India to arrive at a decision upon the course which it will be most advisable to follow, His Excellency the Governor in Council resolves to assemble the following Committee to report on the matter at an early date, *viz*:—

Colonel R. H. Sankey, C.B.,R.E.,	President.
Colonel J. O. Hasted, R.E.,	Members.
Lieutenant J H. Taylor, R.N.R.,	
T. E. Marshall, Esq.,	
F. N. Thorowgood, Esq., M.Inst.C.E.,	
N. St. B. Beardmore, Esq.,	
Major C. Bowen, R.E. ...	Scretary.

2. As laid down in paragraph 4 of the Secretary of State's Despatch No. 10, dated 8th March 1883, so far as the engineering questions involved are concerned, the views of the Committee consulted under Lord Hartington's instructions are to be accepted as closing the discussion on the principle of restoration to be followed; but as there are two distinct methods of applying the general principles to the seaward arms of the work—

(1) as per Section No. 3 of the Home Committee's Report, and
(2) as per Section No. 4,

and, further, as the estimates given are professedly only approximate, the Committee above appointed should submit distinct recommendations, and, as far as possible, a detailed estimate for the sanction of the Government of India.

3. The Home Committee, at the close of their report, observe that the stillness of the harbour would be increased by reducing the width of its entrance from 550 to 450 feet, the cost of which they have included in the estimate; but as, judging from the opinions of masters of vessels and others consulted on a previous occasion, it appears doubtful whether, under the peculiar circumstances of the harbour, the present width of the entrance can be reduced with complete safety, the Committee should enquire particularly into the matter, and, in case their inquiries tend to confirm the evidence already on record, they may consider themselves authorised to submit such alternative scheme as may appear to them feasible, while strictly adhering to the general engineering principles recommended by the Home Committee, and as far as possible limiting themselves to the cost of restoration as now estimated, *viz.*, £480,000.

4. Definite proposals should also be submitted regarding the plant, if any, now to be procured from England, as also the funds which should be provided for in the current and following years so as to insure the early and economical completion of the work.

5. Attention should likewise be given to the provisions necessary for lighting the entrance of the harbour adverted to in the closing paragraph of the Home Committee's report.

Report of the Committee appointed in accordance with above Government Order,—dated 30th April 1883.

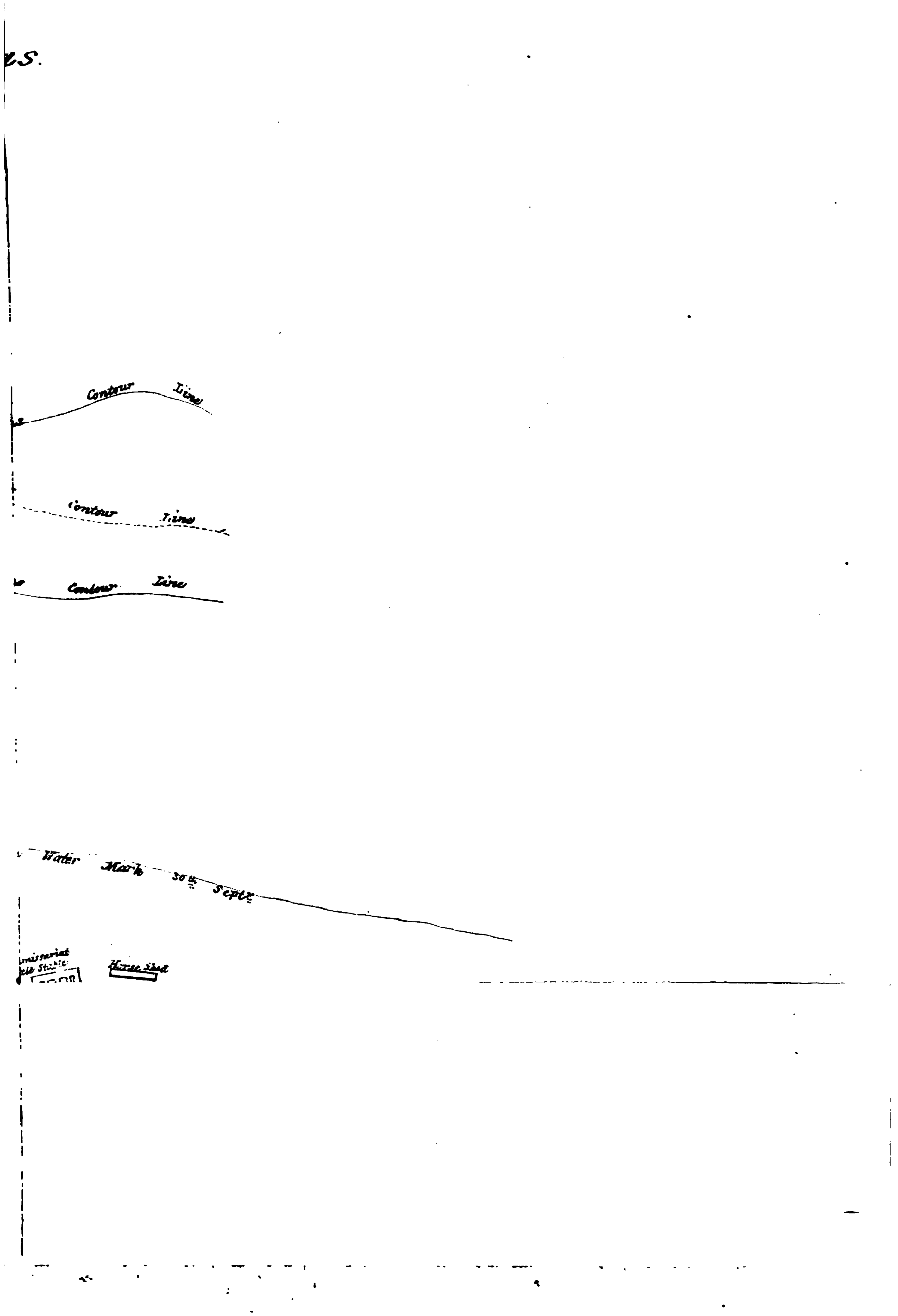
The Committee assembled under G.O., 30th April 1883, No. 1259 W., to consider the best means for giving effect to the proposals made for the completion of the Madras Harbour, have the honour to submit their report for the consideration and orders of Government.

2. The first point claiming attention is the probable cost of completing the works on the several systems suggested by the Home Committee in their report, dated London, 23rd January 1883.

3. As stated in paragraph 25 of that report, the estimates were based generally on the rates of work given by Mr. Parkes, but in some cases the Home Committee assumed higher ones with the results shown in the several appendices, which, though given in sterling, are apparently intended to be converted at two shillings to the rupee.

These estimates are professedly only approximate, or, as expressed by Mr. Parkes in paragraph 4 of his letter of the 10th February 1883, must be viewed "rather as illustrations of the general meaning of the authors, or at most as a basis for approximate estimate than as a basis for instructions to the engineer who will be charged with the execution of the work."

4. In the appendices to the present report will be found estimates prepared by Mr. Thorowgood, which, though still in some degree approximate, will, it is hoped, from the intimate acquaintance of the framer with every detail of the work, prove to be very fairly accurate. It is only in regard to the cost of special plant (for which information is incomplete) that the Committee feel hesitation, but this is not a very material item.



Contour Line
Contour Line
Contour Line
Water Mark 30th Septr
Horse Shed

5. The results as shown may be compared as follows, £1 sterling being taken = R10 in the Home Committee's estimates :—

TABLE No. 1.

Systems for completing the works as given in the Home Committee's Report.	Home Committee's Estimate, including reduction of present Harbour entrance from 550 feet to 450 feet.	PRESENT COMMITTEE'S ESTIMATE—SEE APPENDICES. 1. Retaining the present entrance.	2. Reducing the entrance to 450 feet.	Present Committee's Estimates more by [Column (4)—(2)].
	R	R	R	R
(A.) As per Sections Nos. 1, 2, and 3 (i.e., core of seaward arms constructed on immediate site of present work)	47,92,190	50,93,980	51,85,580	3,93,390
(B.) As per Sections Nos. 1, 2, and 4 (i.e., core of seaward arms constructed on a new base some 60 feet on the harbour side of the work) . . .	42,92,170	45,36,779	46,13,179	3,21,009
(C.) As per Sections Nos. 1, 2, and 5 (i.e., the seaward arms constructed entirely on the random block system)	46,56,000	48,70,472	49,55,672	2,99,672

6. The chief reason for the excess of the present estimates is due to the item for superintendence and contingencies being taken at 15 instead of 10 per cent. in those of the Home Committee, and the rest to a more accurate appraisement of the rates of the work as based on an analysis of the previous accounts, and to the fact that the Home Committee's lengths of pier to be built are 216 feet short of actual requirements.

7. So soon as the system of construction to be adopted has been finally decided on by the Government, it will be desirable to ascertain through the Secretary of State the probable cost of the special plant, which, of course, will vary somewhat with the system, and then recast that portion of the estimate prior to final sanction.

8. The Home Committee, while giving their opinion (paragraph 17) that, as regards the seaward arms from point B on the north pier and E on the south pier, "it would be desirable, if it could be done, to continue the walls on the original foundations," admit that the picking up of the blocks "buried or nearly so in débris, for the purpose of resetting them, or preparing a sufficiently level bed on the site of the destroyed wall, will involve great labour and expense, and possibly even it may be found impracticable to continue the wall on the original foundations."

9. In their present estimate (System A, see table) the Committee have assumed that the plan of picking up and relaying the blocks is practicable, but they can only do so in the sense that while being possible it must of necessity be attended with very great delay and expense.

10. The Home Committee have, as will be observed, strong doubts as to the applicability of the plan, and would apparently unhesitatingly prefer the system B were it not for the curtailment of the area of the harbour which is involved in taking up a space 60 feet in width along the seaward arms.

11. On a full consideration of the state of the present work, the Committee are of opinion that it would be most undesirable to attempt to erect the new superstructure on the present work, as even where the lower blocks have got displaced or subsided only to a very trifling extent (and it must be feared that considerable displacement exists), all the labour of removing them will of necessity have to be gone through, if, as specified, the wall has to be so relaid as to admit of bonding and clamping with iron throughout.

12. All such work, it must be remembered, has to be carried out by the tedious, expensive, and in many respects unsatisfactory agency of divers, to say nothing of the time occupied in slinging and removing each individual block and subsequent resetting.

13. If, therefore, the choice of systems is to be confined to (A) and (B), the Committee have no hesitation in recommending the latter, as the saving in outlay would be R 5,72,401 (see Table No. 1), and in time not much less than a year. The small curtailment of the area of the harbour would practically be inappreciable, and should not, they consider, militate against such undoubted advantages.

14. But before arriving at a final decision regarding the most approved method of construction, it is necessary to consider the objections which have been urged against System (C), which the Home Committee, paragraph 20 of their report, admit to "possess advantages," and to be, as regards construction, "a safe system to follow."

15. The first objection, if, indeed, it can be called one, is, that "it would be necessary to build a short length of wall at the end of each pier upon which to place the entrance lights." Such small addition could be readily made to the work at any time; but it may be observed that at present there is no need for such, as vessels are frequently taken out of harbour whenever required by the aid of two common signal lanterns carried on boats stationed at each of the entrance buoys. The departure of vessels, moreover, after 9 P.M. has been prohibited by law with the sanction of the Government of India. The question of such additions to the ends of the piers may therefore be left out of consideration.

16. The second objection against the random block system is that "owing to the size of the vacuities, amounting to between one-third and one-fourth of the mass, the seas may pass through sufficiently to produce some disturbance inside," and that "the sheltered area being limited, it is important that the whole space should be as quiescent as possible."

17. This objection would no doubt have much weight were the proposal to construct the core of the work *de novo* and throughout with random blocks; but the fact appears to have been overlooked that already the core has been constructed on the monolithic system, and that however the wall may be in places distorted and the material displaced, the blocks are, as a rulee so far in position as effectually to arrest any movement of translation in the seas which impinge on the break-water.

18. Local experience shows conclusively that at present no wave undulations occur *through* the present wall. The seas which enter the harbour come through the entrance and through the gaps in the damaged portions, and the Committee consider that beyond some percolation through the mass of the upper blocks only it would be impossible for a forward movement to be transmitted to the water inside the harbour.

19. It must be borne in mind that during heavy storms the top water of the seas, which is discharged over the work into the harbour, not only has its forward momentum destroyed, but as a fact must, by raising the general level of the water inside occasion an outward flow, which of itself must tend to counteract any undulatory movement in the direction of the shore. In the storm of the 12th November 1881 so powerful was the outward current occasioned by the piling up of the water inside the harbour that masula boats which got adrift were carried seaward through the entrance.

20. It is believed that none of the known break-waters of other ports belonging to this type have a solid screen of the character now existing with the Madras Harbour, and consequently that any analogy based upon the effects noticed in works constructed wholly from random blocks must fail in application.

21. Although, therefore, recognizing the force of the objection urged against break-waters composed of loose blocks, the Committee cannot admit its application to the Madras piers if completed under System C, and feel themselves in a position to submit that *primâ facie* there is no valid professional objection to the random block system of construction (C) in this case.

22. The expense as shown in Table 1 (R49,55,672), although less by R2,30,000 than System (A), exceeds that of System (B) by R3,42,000; but in the opinion of the Committee there are advantages connected with this method of construction which fully outweigh this apparent saving—

First.—As regards the time required for completion of the works, it is considered that from there being no need to employ divers and machinery in clearing the débris, levelling the base, &c., at least a year would be saved.

Secondly.—One large crane of special design on each pier would suffice for the whole work, whereas with the Systems A and B two additional cranes will be needed for forming the "wave-breakers."

Thirdly.—Comparatively small material may be employed for the hearting of the mounds, reserving the heavier blocks for the outer and more exposed portions.

Lastly.—And this is a matter of great importance; the requirements of all future repairs, both in respect to the superintendence and material to be maintained, would be simplified by the absence of a special diving staff.

23. In this connection it is only necessary to draw attention to the fact that, in case the work is completed on either of the monolithic Systems (A) or (B), the repairs of breaches (should such occur) of the seaward arms must occasion great delay and expense from the difficulty of access to the foundations with divers, and from the necessity of maintaining in readiness for all emergencies a skilled diving establishment. Not only so, but disastrous results might easily be produced where, as is not unknown, a second severe storm follows in the wake of the first. If such should happen with unrepaired breaches in the monolithic work, the flanks would almost certainly be destroyed, and the mischief might easily extend in such a manner as to call for very serious outlay.

24. Looking, therefore, to the favourable opinion expressed by the Home Committee as regards the safety of the random block system, and the many attendant advantages above pointed out, the Committee give a decided preference to this method of construction of the three adverted to in the report under consideration.

25. The Committee now proceed to consider the subject submitted for their opinion in paragraph 3 of G. O. No. 1259 W., as to the propriety of reducing the width of the present entrance from 550 feet to 450 feet, and to submit an alternative scheme, should such reduction appear to be undesirable.

26. In reference to the feasibility of narrowing the width of the entrance in the manner proposed, the Committee have been favoured with the following recorded opinion of two of their members, the Master Attendant and Deputy Master Attendant.

27. These officers observe :—" As regards the proposal of the Home Committee to narrow the entrance 100 feet, we consider that it will render it difficult and dangerous to a degree out of all proportion to any advantage that can be gained by it. A large amount of sea and swell must always enter from the eastward, and no comfort to the ships or the boating operations or to beach improvements can be expected till this evil is removed. The completed harbour walls existed long enough to teach this lesson. This is the opinion of all nautical men who have been consulted, and especially the Harbour Master, who has daily opportunities of judging and appreciating the difficulties that attend the entry of large steamers (many of them over 400 feet long) even with the present width."

28. With this very distinct opinion of the professional officers before them, an opinion the validity of which, it may be observed, has long impressed itself on all who have had an opportunity of witnessing the effect of the waves which come in by the present entrance, the Committee have felt that their duty would be very inadequately performed if they left unnoticed this blot on the present scheme, or if they disguised from the Government their clear opinion, not only as to the infeasibility of narrowing the present entrance, but as to the vital necessity for closing the latter completely if a quiet harbour is to be secured.

29. No matter what the direction of the wind, the unceasing swell on this portion of the coast rolls in with the crests of the waves parallel, or very nearly so, to the coast line. In no case is it believed that the angle exceeds 30° to the general line of the coast. The result is that seas enter the present mouth freely, and owing to the small length of the harbour, are not dispersed before reaching the shore at its base. The action is, of course, greatly intensified during storms, and particularly with the wind from the east. At such times the sea inside the harbour, though not so high as outside, is certainly of a dangerous character, being exceedingly broken. Taking these and other facts into consideration, the Committee have to record their opinion that unless means be found for closing entirely the present entrance, no radical cure will have been applied to the chief defect of the work as at present designed.

30. In this view they beg now to submit a plan for the completion of the harbour (see annexed drawings and estimates D, E, F), the leading features of which are—

(1) The opening of a new entrance 500 feet in width, in from 7 to 7½ fathoms of water at the north-east angle of the harbour.

(2) The closing of the present entrance.

31. Before stating the cost and advantages of this proposed arrangement, the Committee desire to draw attention to one or two matters which, while not in reality interfering with constructive details as recommended by the Home Committee, may show how these can be modified without disadvantage.

First, as regards the amount of protection to be given to the portions from the shore to point B on the north, and to point E on the south pier. The Home Committee adopt Section No. 2 (Drawing No. 2) for both alike, but, while admitting the expediency of such additional protection for the north, there is nothing to show that such is needed on the south pier. Not only has the seaward face here not in any way been attacked, but there is apparently no probability that such will occur in any storm that may arise on the coast.

The heaviest seas yet observed have invariably been from the north and north-east, and again on the south the sand accumulations already protect the work for a considerable distance and show a tendency to advance seaward along this pier.

32. The proposed wave-breaker of rough blocks may therefore, in the opinion of the Committee, be omitted on the south arm with safety and the expense saved.

33. The next point is the proposed cap of concrete, 6 feet in thickness, along the same portions of both piers. In reference to this the Home Committee, in paragraph 21, observe that " raising the walls by concrete in mass will be the last process, as that portion of the work can only conveniently be done by beginning it at the outer extremities of the walls and working back towards the shore."

34. When it is remembered that using Systems (A) or (B) four years must certainly (and possibly five or even six years may) elapse before the remodelled piers are sufficiently advanced to receive as the finishing work this cap of concrete, it is clear that the Home Committee, though considering it desirable in many respects, and chiefly as a means for keeping seas from breaking too freely over the piers, did not attach any very indispensably constructive value to this portion of their design.

35. It is fair, in fact, to conclude that if constructively essential to the stability of the work, this concrete cap should advance *pari passu* with the rest of the work.

36. The Committee, in offering this remark, have no desire to interfere in any way with this portion of the design so far as concerns the seaward arms, where they believe that raising the walls in the manner proposed to 12 feet above high water will prove of very sensible value.

37. As regards, however, the piers from the shore to points B and E, they are satisfied, from the effects of the waves on these portions, as hitherto observed, that the proposed cap would be of no material advantage. From the way in which the waves approach the coast the piers are, as a rule, normal to their direction, with the result that only a comparatively small amount of water comes over them into the harbour, the great mass being invariably, it may be said, poured over the seaward arms. Such being the case, the Committee consider that this block of concrete may with complete safety be omitted from the portions indicated.

38. Towards meeting the expense of opening and protecting the proposed new entrance to the north-east and closing the existing entrance there would be savings on the two items mentioned, *viz.*—

(1) By the omission of the random block wave-breaker along the south pier to E.

(2) By the omission of the concrete cap from the shore to B on the north and to E on the south pier. The actual savings in cash outlay due to these modifications will be found further down, where is shown the probable cost of the harbour as thus completed, and here it will be desirable to advert to the formation of the proposed new entrance at the north-east angle of the harbour.

39. The position is shown on the tracing to lie between the 7 and 7½-fathom lines, and the width to be 500 feet.

40. On this point the Master and Deputy Master Attendants have supplied the following observations:—

"(1) The proposed entrance to the north may safely be narrowed to 500 feet, because the cross-currents and winds that affect the east entrance will no longer exercise a troubling effect.

"(2) The proposed entrance to the north in 7 fathoms will allow of the whole deep water space being utilized, which is impossible under the conditions of the eastern entrance, and deep water space is especially valuable in a basin like the Madras Harbour."

41. The Committee have adopted the conclusions as above stated, and also one to the effect that the protecting horn should be not less than 600 feet in length, carried out tangentially to the curve at the north elbow, and curved slightly to the east, in order the better to deflect the seas from the entrance and from the north arm, and to give a *vena contracta* form of entrance for the more easy passage of vessels. Looking to the general parallelism of the crests of the waves to the shore, it is doubtful whether in practice so long a protective horn will be found to be indispensable, but as it is better to err on the safe side, the Committee have provided for one 600 feet long in the estimate.

42. As a matter of detail it may here be mentioned that the concrete blocks which now encumber the work at this point will in all probability be broken up by dynamite, and the débris with the rubble base, down to a depth of 6 fathoms, removed by dredging.

43. The closing of the existing entrance will proceed so soon as the new north-east one has been worked out, and the final operation will be the construction of the horn. As the whole of the seaward arms can by this manner be dealt with continuously, only one titan crane would be needed, in case either of the Systems (A) or (B) is adopted, or one set of travellers if System (C) be decided on.

44. The following are the financial results of the above method of dealing with the harbour according to the system which may be approved:—

	R
(1.) If completed on Sections 1, 2, and 3, the present entrance closed also by Section No. 3 and entrance on north opened	54,18,717
(2.) If completed on Sections 1, 2, and 4, the present entrance being closed on Section No. 3	50,26,348
(3.) If completed on Sections 1, 2, and 5, the present entrance being closed on Section No. 5 (random block-work)	51,42,636

(The cost of wave-breaker on south arm and concrete cap to both arms is omitted in these estimates.)

For detailed estimates see the appendices.

45. For the reasons before assigned, the Committee would strongly recommend the completion of the work on the random block system.

46. The Committee would here solicit attention to the following recorded observations by the Master and Deputy Master Attendants in reference to the above proposals:—"We," they observe, "consider that if the sea-face is closed, and a height of 12 feet given to the sea-wall, that much of the character of a protective work to shipping, under which sanction to it was first obtained, will be restored, and the question of sending ships to sea on approach of bad weather need no longer be considered."

47. To those who are acquainted with the fact that the main object of the late Lord Hobart in pressing the necessity of a harbour on the attention of the Secretary of State was the beneficent and humane idea of sheltering vessels in port from the dire effects of the cyclones, which unhappily but too often visit the Coromandel Coast, and which since the advent of European shipping have occasioned such fearful losses in life and property, the true import of the proposals now submitted will, it is hoped, be sufficiently obvious.

48. It is believed that Mr. Parkes never claimed for his work the character of a harbour of protection, and certainly the cyclone of the 12th November 1881 tended to show that, far from being an efficient protection to the shipping inside, it might on such occasions prove to be, as it were, a trap from which escape might be difficult and at times perhaps impossible.

49. The fear, indeed the certainty, that such would prove to be the result has, it may be said, imposed a much more severe responsibility on the Marine authorities than was the case when no harbour existed.

50. With the present eastern entrance unchanged, this extreme danger to shipping, and this terrible responsibility for life and property, must remain, no matter what the system adopted for the completion of the rest of the work; and to allow matters to remain as they are will add the evil of a perpetual and dangerous reef in front of Madras in the form of the present ruined piers.

51. Under the proposals now submitted, not only will, it is believed, the unexpected boon of a harbour of protection be conferred on Madras, but Imperial significance will be given to this great work, which, if finished in the manner suggested, could in time of war afford shelter and protection to the vessels of Her Majesty's navy, as also to all merchantmen who could make the port.

52. The Home Committee, in many parts of their report, correctly draw attention to the unduly small area of the present harbour, not much more than the outward half of which is suited for mooring vessels of any draft; but, as will no doubt at once be recognized, the proposals above made must, by affording the means whenever desired, of dredging out the shallow portions to any required depth, admit of doubling the useful area.

53. An operation of this character, it is almost needless to say, could never be carried out so long as the present entrance remains open, the disturbance inside the harbour being such that, with the exception of a very few days each year, would render dredging operations impossible, excepting at an altogether prohibitive outlay.

54. Not only would the advantages here enumerated be secured, but in many other respects, such as the possibility of mooring ships much closer together than is at present feasible, bringing ships much closer to the shore, establishing wharves, jetties, &c., facilities to the trade of the port may be increased indefinitely.

55. The total cost of the work remodelled as recommended will, as shown, be R51,42,636 as compared with that of the Home Committee System A, R50,93,980. Practically, therefore, the two methods of dealing with the harbour may be considered as costing much the same.

(Signed) R. H. SANKEY, *Colonel, R.E.*
(„) J. O. HASTED, *Colonel, R.E.*
(„) J. H. TAYLOR, *Lieutenant, R.N.R.*
(„) T. E. MARSHALL.
(„) F. N. THOROWGOOD.
(„) N. St. B. BEARDMORE.
(„) C. BOWEN, *Major, R.E., Secretary.*

20th June 1883.

Note by Mr. Beardmore on paragraph 21.

I consider it important that, in order to adequately protect the proposed north-east entrance the protecting break-water should be at least 650 feet in length measured from the eastern tangent point of the north pier, and that if it is thus constructed, an excavation through the old rubble base of 400 feet in *bottom* width will prove to be sufficient, and indeed better in checking north-eastern seas from entering the harbour.

(Signed) N. St. B. BEARDMORE.

Appendix to report of abov Committee:—Estimate of cost of restoration as proposed by the Home Committee, and as modified by the Special Local Committee.

(Quantities an rices by the Superintendent of the Madras Harbour Works.)

NOTE.—The total lengths of the two piers, as shown by the figured dimensions in the plan accompanying the Home Committee's Report, do not agree with the actual lengths of work to be executed, but are 218 feet short of such lengths.

The following estimates are made with the corrected lengths for obtaining an entrance of 450 feet, *viz.*, 3,916 feet for the north pier and 4,020 for south pier.

The lengths for each section of the Committee's proposal therefore are altered thus:—

	North Pier	(On plan).	South Pier	(On plan).
Section No. I	426	(400)	680	(650)
Section No. II	1,800	(1,800)	1,750	(1,750)
Sections Nos. III, IV, V	1,690	(1,600)	1,590	(1,520)
TOTAL	3,916	(3,800)	4,020	(3,920)
Difference	116 feet.		100 feet.	
Total Difference	216 feet.			

Both dimensions are shown in the plan accompanying these papers.

ESTIMATE FOR SECTION No. 1.

	Feet.
Length—North Pier	426·0
South „	680·0
TOTAL	1,106·0

Per lineal foot of pier.

	R	a.	p.
Additional rubble—18·0 × 6½ × ½ = 58½ c. ft. = 3 tons at R1-8-0	4	8	0
Concrete topping—24·0 × 4½ × 1·0 = 108 = 4 c. yds. at R12-0-0	48	0	0
Iron cramps—44 lb per lineal foot at ½ anna	1	6	0
Total per lineal foot	53	14	0

For both Piers.

1,106 lin. ft. at R53-14-0	59,585	0	0
Deduct for 480 lineal feet at south pier, thoroughly protected by sand and not needing rubble, Rubble 480 ft. with 3 tons to 1 ft. = 1,440 tons at R1-8-0	2,160	0	0
	57,425	0	0

Total for Section No. I, Rs. 57,425.

SECTION No. II.

	Feet.
Length—North pier	1,800
South do.	1,750
	3,550

Per lineal foot of pier.

Additional rubble—

	c. ft.
110·0 × 8½ × ½ =	467½
55·0 × 5½ × ½ =	151¼

	R	a.	p.
618¾ = 31 tons, at R 2	62	0	0
Concrete blocks in wave-breaker— 50 × 20/2 × 1·0 = 500 c. ft. = 18·5 c. yds., at R 11	203	8	0
Concrete topping— 24·0 × 6·0 × 1·0 = 144 = 5 ⅓ c. yds., at R 12	64	0	0
Per lineal foot	329	8	0

	R	a.	p.
For both piers 3,550, at R 329-8-0	11,69,725	0	0
Add for 415 feet of piers to be cramped at R 1-6-0 per foot . . .	570	10	0
Total value of work, Section II . . .	11,70,295	10	0

Section No. III.

	Feet.
Length—North pier	1,690
South do.	1,590
Total . . .	3,280

Per lineal foot of pier.

Additional rubble—

79 × 18 × ½ = 711
65 × 17½ × ½ = 568¾
8·0 × 2·0 = 16
63·0 × 2·0 × 1·0 = 126

		R	a.	p.
1,421¾ cubic feet = 71 tons, at . .	R 2 =	142	0	0
Concrete blocks in wave-breaker—				
65·0 × $\frac{28'}{2}$ = 28 cubic yards, at	„ 11 =	308	0	0
Concrete blocks in regular work—				
28·0 × 6·0 × 1·0				
24·0 × 24·0 × 1·0 = 744 cubic feet 27½ cubic yards, at .	„ 11 =	303	0	0
Preparing base by removing old blocks, &c., per lineal foot at .	„ 134 =	134	0	0
Concrete topping—				
24·0 × 5·0 × 1·0 = 4½ yards at	„ 12 =	54	0	0
Concrete bags—				
20·0 × 2·0 × 1·0 = 40 cubic feet = 1½ cubic yards, at .	„ 11 =	16	8	0
Two cramps or 88 lb. per foot, at ½ anna per lb.		2	12	0
		960	4	0
Deduct for old blocks recovered in foundation one-seventh of the wave-breaker at 4 yards per foot, at	„ 11	44	0	0
Total per lineal foot . .		916	4	0

Section No. III, 3,280 lineal feet, at R916-4-0 per foot, R30,04,480.

Section No. IV.

Alternative Section per No. III. Total length, 3,280 feet. Per lineal foot of pier.

Additional rubble—

c. ft.
62·0 × $\frac{24}{2}$ × 1·0 = 744
50 × $\frac{24}{2}$ × 1·0 = 600

		R.	a.	p.
1,344 = 67 tons at	R2 =	134	0	0

Concrete blocks in wave-breaker—

c. ft.
40·0 × $\frac{26}{2}$ × 1·0 = 520

Concrete blocks in regular work—

28·0 × 6·0 × 1·0 = 168
24·0 × 24·0 × 1·0 = 576

		R.	a.	p.
1,264 = 47 cubic yards, at . .	R 11 =	517	0	0
Concrete topping—				
24·0 × 5·0 × 1·0 = 4½ cubic yards, at	„ 12 =	54	0	0
Preparing base at per lineal foot	„ 40 =	40	0	0
Apron bags 20·0 × 2·0 × 1·0 = 1½ cubic yards, at	„ 11 =	16	8	0
Two cramps to each course, per foot	=	2	12	0
Per lineal foot . .		764	4	0

3,280 feet of piers at R764-4-0 = R. 25,06,740.
Total per Section No. IV, R25,06,740.

Section No. V.

(Random Blockwork.)

Length same as No. III and No. IV, 3,280 feet.

Additional rubble—

	c. ft.
90·0 × 2·0 × 1·0 =	180·0
60·0 × $\frac{17}{2}$ × 1·0 =	510·0
85·0 × $\frac{18}{2}$ × 1·0 =	765·0
37·0 × $\frac{19}{2}$ × 1·0 =	351·6
50·0 × $\frac{17}{2}$ × 1·0 =	425·0

	R.	a.	p.
2,231·6 = 112 tons, at . . . R 2 =	224	0	0
Concrete blocks at random—			
60·0 × $\frac{24}{2}$ = 720			
42·0 × $\frac{18}{2}$ = 378			
30·0 × 24 = 720			
1,818 = 67½ cubic yards, at . . . . . R11 =	740	0	0
Concrete topping and bags—			
30·0 × 8·0 × 1·0 = 240 = 9 cubic yards, at, say . . „ 12 =	108	0	0
	1,072	0	0
Deduct for random blocks in ruined work about—			
60 × $\frac{18}{2}$ × 1·0 = 20 cubic yards, at . . . . . „ 11 =	220	0	0
Per lineal foot . . .	852	0	0

For both piers, 3,280 feet, at R852 = R27,94,560

ALTERNATIVE PROPOSALS.

Estimate for full Section No. III (without any old work) to be used for closing eastern opening. Per lineal foot of pier.

Memo.—The rubble base is to extend 33 feet from edge of blocks to top of slope on harbour side.

Rubble base in 48 feet water—

75 × $\frac{21}{2}$ = 787½
75 × $\frac{50}{2}$ = 1,875
61 × 26 = 1,586
42 × $\frac{20}{2}$ = 420

	R	a.	p.
4,668½ = 233 tons, at R2 = ...	466	0	0
Value of No. III Section without taking credit for old blocks per foot and without R134 for preparing base	826	0	0
Per lineal foot	1,292	0	0
Taking 500 feet as the additional amount of rubble base required at R466 = ...	2,33,000	0	0
And 550 feet for blockwork at R826 = ...	4,54,300	0	0
Total for closing entrance with No. III Section .	6,87,300	0	0

For making a Northern Entrance.

Excavation of rubble for 600 feet in length—

40·0 × 3·0 = 120·0 cubic feet.
41·0 × $\frac{19}{2}$ = 389·6 „
54 × 17 = 918·0 „
43 × $\frac{15}{2}$ = 322·6 „

	R	a.	p.
1,750·0 × 500 = 32,407 c. yds., at R4 = . . .	1,29,628	0	0
Excavation and removal of blocks—			
28·0 × 20 = 560 × 500 = 10,333 c. yds., at R8 = . . .	82,664	0	0
	2,12,292	0	0

Building a protective arm, 400 feet long, in Section No. 3, but without heavy charge for preparing base.

	R	a.	p.
600 of full Section No. III, at R1,292 per foot =	7,75,200	0	0
Deduct for value of old blocks recovered enough to make one-fourth wave-breaker or 7 cubic yards, at R11 = R77, for 400 feet	30,800	0	0
	7,44,400	0	0
Add for pier head-work	20,000	0	0
	7,64,400	0	0
	2,12,292	0	0
Excavation as above	9,76,692	0	0

Savings effected by making north-east entrance owing to there being less pier to build.

		R	a.	p.
(a) In Section No. III— 600 feet, at R916-4-0 per foot		5,49,750	0	0
(b) In Section No. IV— 600 feet at R764 per foot		4,58,400	0	0
Deduct lump sum for extra work in crossing over line of north pier for outer horn		50,000	0	0
	Net	4,08,400	0	0
(c) In Section No. V— 600 feet at R852		5,11,200	0	0

Whole Section No. 5 for closing eastern entrance and building outer horn.

Rubble base (48 feet per lineal foot water)—

$$65·0 \times \frac{21}{2} = 682·6$$
$$155·0 \times \frac{27 + 24}{2} = 3,952·6$$
$$72·0 \times \frac{25}{2} = 900·0$$

		R	a.	p.
5,535·0 = 276 tons, at	R 2 =	552	0	0
Concrete blocks (as before) 67½ cubic yards, at	„ 11 =	740	0	0
Concrete topping and bags, 9 cubic yards, at	„ 12 =	108	0	0
		1,400	0	0

For closing entrance—

		R	a.	p.
500 feet rubble work, at R552 per foot =		2,76,000	0	0
500 feet blockwork at R848 ditto =		4,66,400	0	0
		7,42,400	0	0
For building extra horn, 600 feet at R1,400	6,40,000			
Deduct for old blocks	30,800			
	6,09,200			
For work in pier head	20,000			
		6,29,200	0	0
		13,71,600	0	0

Saving by doing away with south pier wave-breaker to 1,750 feet and with concrete topping on Sections I and II.

		R	a.	p.
No. I Section— 1,106 feet concrete top, at	R48 =	53,088	0	0
No. II Section— 3,550 feet concrete top, at	„ 64 =	2,27,200	0	0
Wave-breaker, south pier— 1,750 feet blocks, at	R203-8-0 =	3,56,125	0	0
Rubble 1,780 feet, at	R62 =	1,08,500	0	0
		7,44,913	0	0

SUMMARY OF ESTIMATES.

					R
(A.)	Restoring as per	Sections I, II, and III	with 450	feet entrance	51,85,580
	Ditto	ditto	with 550	ditto	50,93,980
(B.)	Ditto	Sections I, II, and IV	with 450	ditto	46,13,179
	Ditto	ditto	with 550	ditto	45,36,779
(C.)	Ditto	Sections I, II, and V	(450 feet cut)		49,55,672
	Ditto	ditto	(550 ditto)		48,70,472

ALTERNATIVE PROPOSALS.

With 500 feet entrance to the north-east abolishing concrete *capping on inner portion* of work, and wave breaker *to inner portion* of south pier.

		R
(D.)	Restoration being carried on as Sections I, II, and III, and extra work built as Section III	54,18,717
(E.)	Restoration to be carried on as in Sections I, II, and IV, extra work being as Section III	50,26,348
(F.)	Restoration and extra work to be done as in Section V (Random Work). Memo.—This will be the *quickest* work	51,42,636

For blocks on stock a credit of R1,30,630 may be taken for every section.
R60,000 added for extra titan roads and rails omitted in detailed estimate.

SUMMARY OF ESTIMATES.

(A.) Estimate for restoring Harbour as proposed by Committee, in Sections I, II, III.

	R
Total value for Section No. I	57,425
Do. do. No. II	11,70,295
Do. do. No. III	30,04,480
	42,32,200
Plant—	
Two titan cranes complete, at R45,000	90,000
Two cranes for setting wave-breakers, at R30,000	60,000
New railway lines, 230 tons of permanent-way material, at R100	23,000
200 tons titan rails, at R100	20,000
4,000 sâl-wood sleepers, at R4-8-0	18,000
16,000 lineal feet titan roads, at R4	64,000
One Goliath crane, restored	2,000
	45,09,200
Add 15 per cent. for Establishment and Contingencies	6,76,380
	51,85,580
If with 550 feet entrance, deduct 100 feet, at R916	91,600
	50,93,980

SUMMARY OF ESTIMATES.

(B.) Estimate for restoring harbour as proposed by Committee in Sections I, II, and IV.

	R
Total value for Section No. I	57,425
Do. do. „ II	11,70,295
Do. do. „ IV	25,06,740
	37,34,460
Plant, as for Sections I, II, and III	2,77,000
	40,11,460
Add 15 per cent. for Establishment and Contingencies	6,01,719
	46,13,179
If with 550 feet entrance, deduct 100 feet, at R764	76,400
	45,36,779

SUMMARY OF ESTIMATES.

(C.) Estimate for restoring Harbour as proposed by Committee in Sections I, II, and V (Random Blocks).

	R
Total value for Section No. I	57,425
Do. do. „ II	11,70,295
Do. do. „ V	27,94,560
	40,22,280

		R
Plant—		
Two special titan cranes capable of setting regular work, and overhanging enough to build random blocks		1,60,000
Other plant as before, less the two extra cranes		1,27,000
		43,09,280
Add 15 per cent. for Establishment and Contingencies		6,46,392
		49,55,672
If with 550 entrance, deduct 100 feet, at		85,200
		48,70,472

COMMITTEE'S ALTERNATIVE PROPOSALS.

First Alternative.—To close present entrance by Section No. 3, and open one to the north, extending the eastern part of the break-water 400 feet as an overlap to the entrance.

		R
(D.) Estimate for repairing by Sections I, II, and III, see Summary of Estimates (A)		42,32,200
Deduct 100 feet for making 550 feet entrance		91,600
		41,40,600
Add—		
For building across entrance		6,87,300
Do. 400 of protecting arm		7,64,400
Excavating and opening north entrance		2,12,292
		58,04,592
Deduct saving as shown (*a*) on page 167	5,49,750	
Also saving as shown on page 167	7,44,913	
		12,94,663
		45,09,929
Closing north entrance.		
Plant—		
One titan crane	45,000	
One crane for wave-breaker	30,000	
Other plant as in Summary of Estimates (A)	1,27,000	
		2,02,000
		47,11,929
Add 15 per cent. for Establishment and Contingencies		7,06,788
GRAND TOTAL		54,18,717

(E.) Estimate for closing eastern entrance and opening one to the north, the work being restored mainly on Sections I, II, and IV.

		R
Value of restoring work by I, II, and IV (as shown in Summary of Estimates (B)		37,34,460
Deduct for 100 feet to restore 550 entrance		76,400
		36,58,060
Add—		
For building across entrance		6,87,300
600 feet of protecting arm		7,64,400
Excavating and opening northern entrance		2,12,292
		53,22,052
Deduct—		R
Saving as shown (*b*), page 167	4,08,400	
Also as shown on page 167	7,44,913	
		11,53,313
		41,68,739
Plant as before		2,02,000
		43,70,739
Add 15 per cent. for Establishment and Contingencies		6,55,609
GRAND TOTAL		50,26,348

(F.) Closing eastern entrance and opening one to north, with Sections I, II, and V.

Memo.—The entrance is supposed to be closed and the extra protective built on Section 5.		R
Restoring work, Sections I, II, and V with 450 feet entrance		40,22,280
Deduct for 550 feet entrance, 100 feet		85,200
		39,37,080
Add—		
Building across entrance		7,42,400
Do. extra protective arm		6,29,200
Excavation in north pier		2,12,292
		55,20,972
Deduct—	R	
Saving as shown (c) on page 167	5,11,200	
Also as shown on page 167	7,44,913	
		12,56,113
		42,64,859
Plant—		
One special titan	80,000	
Other plant as before	67,000	
		2,07,000
		44,71,859
Add 15 per cent. for Establishment and Contingencies		6,70,777
		51,42,636

Detailed Remarks on Prices and Methods of carrying out work suggested.

Rubble Stone for Base and Foreshore.—The rubble for base and foreshore is to be clean, hard syenitic rock from Pallâvaram, similar to what has been used hitherto from that quarry. The price is generally taken at R2 per ton deposited in the sea, but for the shore ends of the piers, for protective work, R1-8-0 per ton has been taken. The ton has been taken as 20 cubic feet, and this is arrived at by frequent measurements and weighings. The price is based on what has already been done in depositing 800,000 tons of rubble, the cost of which varied from R1-8-0 to R2-4-0 per ton, the latter price being exceptionally high. The rubble will be deposited from large boats propelled by oars; also by being thrown from the piers and by being tipped by the overhanging crane. No steam hopper barges will be needed. The stones will vary in weight from 3 lbs. to 300 lbs.

2. *Concrete Blocks.*—The concrete blocks will be similar in composition to those made latterly for the damaged piers, of which 12,563 cubic yards are now on stock. The Madras local cement may, however, be used as much as possible, but this does not materially affect the price.

The cost of the concrete blocks per cubic yard has latterly been R8·90 in the yard, and the cost of setting by means of divers has been sometimes below R2, and sometimes a little above R2 per cubic yard, including all charges. Therefore the price chosen in the estimate of R11 is fair.

Concrete Topping and Concrete in Bags.—This has been taken at R12, as there will be more waste of cement in mixing, and the materials will have to be carried along the piers for mixing *in situ*, thus adding to oheir cost before they are converted into concrete.

Iron Cramps.—Iron cramps are taken at ½ anna per lb. fixed in the blocks with cement. The price is based on actual work done.

Preparing foundations on site of ruined work.—This is a difficult item to estimate, as we have no similar experience. We know that it will be very tedious and difficult. There was a time in the north pier work when there was 7 feet of excavation to be carried on in laterite rubble. This reduced progress to nearly a standstill, and took a very strong diving force. The amount of material to be shifted was more than equal to a course of blocks. It was found to cost R134 per lineal foot. This price has been selected as the cost per lineal foot of preparing foundation in ruined work. It may cost twice as much.

Method of Setting Blocks in Sections III and IV.—It is supposed that for the actual piers two titan cranes will be required, in which there should be some alterations and improvements. For depositing the blocks in the wave-breakers other cranes should be used, of special design, with their overhang extending on each side of the blocks. They should be capable of holding 30 tons with an overhang of 40 feet.

The blocks for the wave-breakers should be "tripped" and not lowered by Lewis bolts.

Crane Roads.—The roads on which the setting machines (titan or similar cranes) travel are to be continuous. They should be 70 lb. flat-bottomed rails, fastened by fang-bolts (not spikes) to teak longitudinal timbers 14″ × 10″. These timbers to be fixed to the blocks and built in.

Crane for Random Blockwork.—The cranes or crane required for this work must be one with enormous scope. It should be capable of carrying 30 or 40 tons at a radius of 50 feet, and should be on a circular girder to "jib" completely round. It will be absolutely necessary to deposit the blocks as far away from the centre line as possible; otherwise there will be no chance of retaining an even and solid road for the crane to advance upon.

Construction of Random Work.—To within 15 feet of low water no doubt rubble stone may be used as a hearting to the outer slopes of random work. But above this nothing but heavy blocks should be used, except for purposes of leveling up. If the individual blocks at the level of breaking sea are too light, say less than 25 tons, there is no stability in the random mound. At 6 feet above H. W. the work must be levelled and concreted up with bags, ready to receive the top course of blocks which must be brought up level enough to carry a railway, as well as the crane roads.

Estimate of Plant.—The estimate for plant is nothing more than a guess based upon the *known* cost of cranes, rails, sleepers, &c., as given by previous experience on these works. As the cranes are purchased as complete machines for a lump sum, it is not possible to enter into details except in communication with the builders in England.

Establishment and Contingencies.—It is believed that 7½ per cent. will be ample for "Establishment," but as in former experience 2½ per cent. was far too little for "Contingencies," it is judged safer to make the charge for the latter also 7½ per cent., which it is hoped will be more than sufficient.

Note by G. L. MOLESWORTH, Esq., Consulting Engineer to the Government of India for State Railways, on the two Reports of the Home and Madras Committees on the Madras Harbour Works,—dated 17th July 1883.

In the following remarks I propose for the sake of brevity to term the Committee appointed by the Secretary of State in July 1882, and consisting of Sir John Hawkshaw, Sir John Coode, and Professor Stokes, the "*Home Committee,*" whilst I shall term the Committee appointed in Madras on the 30th of April 1883 the "*Madras Committee.*"

The recommendations of the Home Committee may be dealt with under four separate heads—

1st—The raising of the height of the break-water from 6 to 12 feet above high water level.

2nd—The strengthening of the sides of the harbour.

3rd—The reconstruction of the elbows and faces of the harbour.

4th—The question of the entrance to the harbour.

To deal with these *seriatim*—

1st.—I am of opinion that the raising of the height of the break-water is desirable, and that it will contribute greatly to the preservation of still water within the harbour in times of rough weather.

It appears to me, however, to be unnecessary to raise the level of the break-water, except on the faces and elbows; for, as I have already pointed out in my previous report on the Madras Harbour, the *sides* of the harbour will probably never be exposed to the broadside action of cyclonic waves; and this opinion is confirmed in the report of the Madras Committee, which states that "*no matter what the direction of the wind, the unceasing swell on this portion of the coast rolls in with the crests of the waves parallel or nearly so to the coast,*" nor can it, I think, be otherwise; and the heavier the swell, the greater is the tendency to assume the direction above described. Moreover, if the proposal of the Madras Committee respecting the entrance be adopted, the north side will be still further protected from wave action.

I would therefore suggest a postponement of the raising of both sides of the harbour until further experience has been gained as to the necessity for the work. The raising may be executed at any time; it is not a work that presses, and does not form an integral portion of the reconstruction; and if it be postponed, valuable experience will be gained as to its necessity during the period of reconstruction.

I think, however, the cost of raising the sides might be retained in the estimate as a contingency to which Government may be liable.

The raising of the faces and elbows might be carried on simultaneously with reconstruction.

2nd.—The reasoning which I have applied to the raising of the sides will also hold good to a certain extent with regard to the strengthening of the sides by random blocks thrown down on the sea-side to form a "wave-breaker," for I am induced to think that it will not be necessary to adopt so large a provision as that contemplated in the report of the Home Committee.

In my previous report I suggested that the sides should be protected by throwing down additional gneiss rubble on the sea-side, and I am inclined to think that this will suffice. I should at all events be disposed *at first* to lay down not more than a few hundred feet of "wave-breaker" at that portion of the side which is nearest to the "elbow," and additions may be made to this at any time should it be found necessary.

I should be disposed, therefore, as in the case of raising the sides, to postpone the execution of this portion of the works whilst retaining it in the estimates.

3rd.—The Home Committee has suggested for the reconstruction of the faces and elbows three alternative propositions, namely—

(*a*) Replacing the fallen blocks in their original position, and adding random blocks as a "wave-breaker."

(*b*) Constructing a new wall 60 feet in the rear of the original wall, and adding a " wave-breaker " of random blocks.

(*c*) Depositing random blocks cn the *débris* of the original wall.

Alternative (*a*) is recommended, *if practicable;* but some doubts are thrown by the Home Committee upon the practicability of the plan. The Madras Committee also expresses strong doubts as to its practicability, which I must admit I share; and even assuming its practicability, the Madras Committee considers that it must be attended with very great difficulty and delay, and should on that account be rejected, narrowing down the selection to alternatives (*b*) and (*c*).

Alternative (*b*) is quite practicable, but the Home Committee points out that it will shorten the harbour (already very short), and that it will be undesirable to build on the unconsolidated rubble.

In addition to the objections raised by the Home Committee, I am of opinion that the *débris* of the original wall, irregular as it is, and being in advance of the new wall, would probably set up a very serious wave action of which it is impossible to predict the results. In some places the wall stands to its full height, whilst in other places there are breaches, and the only way of obviating a complicated wave action would be thoroughly to dismantle the old wall and reduce it to an even surface; and this would be a very expensive operation.

Alternative (*c*) "*possesses*" (in the opinion of the Home Committee) " *advantages, and as regards construction is a safe system to follow.*" It is objected to only on account of necessitating short walls at its extremities for entrance lights, and on the ground of admitting through its interstices some disturbance inside the harbour. The Madras Committee, however, points out with much force that these objections are not valid. The entrance lights are not needed, and, even if they were needed, could be arranged for otherwise; and the core formed by the old wall would prevent disturbance in the harbour through the interstices of the random blocks.

The Madras Committee then, considering that there is " no valid professional objections " to the random block system of construction, give a decided preference to alternative (*c*), and with this opinion I entirely concur.

I think, however, that the section proposed needs some slight modification. It is well known that if a wave be deflected, its force will be far less than if it be allowed to break; and waves will be broken by any slope having an inclination less than 1 to 1; whilst from that angle to the perpendicular the wave will not be broken, unless it be nearly on the point of breaking when it reaches the slope. Now the section proposed averages about an inclination of 1½ or 1¾ to 1, and on such a surface the waves will probably break instead of being deflected. Nearly all the French break-waters constructed on the random block system have an average slope of 1 to 1, and I recommend the adoption of that slope in the section to be given to the face and elbows of the Madras break-water when reconstructed. The same reasoning holds good as regards the rubble deposit, which is shown on the section, at an average slope of about 3½ to 1.

The adoption of this slope would give a tendency to convert vertical into horizontal motion, and make the waves to break heavily on the break-water. The lower portion of the wave being restrained, the upper part would be flung heavily on the break-water. I would suggest that *no additional rubble* should be placed on the outside of the section, but that the blocks should be allowed to fill up any deficiencies in the section; this would not entail any larger expenditure of blocks than is at present contemplated, if the French practice of slopes of 1 to 1 be followed; and the section would be safer from disturbance.

I think that the fact that the rubble has been displaced by the wave action shows the necessity for extending the casing of large blocks to that depth.

I enclose typical sections (diagram Nos. 1 and 2) which I recommend as modifications of those which accompany the report of the Madras Committee.

4th.—The Home Committee suggests the reduction of the entrance from 550 to 450 feet in width, whilst those who have had actual experience in working vessels in and out of the harbour consider that this will render the entrance " difficult and dangerous to a degree out of all proportion to any advantage that can be gained by it;" and although from a study of the comparison with other harbours, I am inclined to think that a reduction might be made in the width of the entrance, yet, in the face of so strong an expression from those who have had actual experience, it would be prudent to defer any reduction of the entrance, as I suggested in my previous report, until further experience has been gained; and I think that if two fixed beacons were placed at each side of the entrance as proposed to be reduced by the Home Committee, the necessary experience might be practically obtained before the time arrives for carrying out the reduction proposed.

There is no doubt that even with this reduction there will be a considerable movement within the harbour.

I have calculated the probable intensity of the swell in the harbour at different distances from the entrance and with waves of different initial height outside the entrance. The following tables give the results of my calculations—

Table No. 1.

WIDTH OF ENTRANCE 550 FEET.

Distance from entrance.	Height of swell in harbour when initial height of waves outside is		
	25 feet.	30 feet.	35 feet.
	ft.	ft.	ft.
500 feet	7·32	8·78	10·24
1,000 „	6·68	8·02	9·36
1,500 „	6·26	7·51	8·76
2,000 „	5·92	7·10	8·29
2,500 „ (head of jetty)	5·65	6·78	7·90

Table No. 2.

WIDTH OF ENTRANCE 450 FEET.

Distance from entrance.	Height of swell in harbour when initial height of waves outside is		
	25 feet.	30 feet.	35 feet.
	ft.	ft.	ft.
500 feet	6·40	7·68	8·96
1,000 „	5·79	6·94	8·10
1,500 „	5·37	6·44	7·52
2,000 „	5·04	6·05	7·06
2,500 „ (head of jetty)	4·78	5·74	6·69

These results only give the swell caused by that portion of the wave which passes through the entrance, and do not take into account the disturbing effect of any portion of the wave that may pass *over* the structure.

It will be seen, then, from these tables that with a 30 feet wave outside the harbour the reduction of entrance would approximately reduce the swell at the head of the jetty inside the harbour from 6·78 feet to about 5·74 feet, or in round numbers about one foot.

The "Madras Committee," however, has recommended the closing of the present entrance and opening of a new entrance in the north elbow, this entrance being covered by a projecting break-water curving out from the eastern tangent of this elbow.

The entrance to a harbour at right angles to the general direction of the swell is generally considered to be a very disadvantageous arrangement; for when a vessel is entering such a harbour, half protected by the entrance, and half exposed to the action of a heavy wave, it is liable to be swung round, and strike the entrance before it can recover itself: this is a contingency to which modern vessels from their extreme length are especially liable.

The projecting break-water proposed by the Madras Committee will allow some distance for a vessel to recover itself under these circumstances, but I think scarcely sufficient. Colonel Trevor, the Secretary, suggests an increase to the length of this projection, and I am of

opinion it should be increased not only for covering the entrance, but also in order to allow a vessel to recover itself if struck by a wave when half protected.

I presume that the nautical authorities on the Madras Committee have satisfied themselves as to the practicability of a ship entering the harbour by such an entrance in stormy weather; but I think it would be desirable to refer this question to the highest nautical authorities in India.

Supposing the entrance to be practicable, the change of entrance would doubtless add very greatly to the quiescence of the harbour; but I must confess that I am somewhat sceptical of the *absolute* safety of vessels in Madras Harbour during a cyclone, even under the conditions of having raised the face and elbows and closed the seaward entrance.

Assuming, however, the feasibility of such an entrance, I am of opinion that the form of break-water proposed for covering this entrance requires some modification. In its proposed form it is open to serious objections, involving, as it does, a re-entering curve which would never stand the blow of a cyclonic wave.

I have, in my previous report, adverted to the confluent action of waves along the faces and round the elbows of this break-water, and I annex a diagram (No. 3) showing in black arrows the action of waves on a break-water such as that proposed by the Madras Committee.

It will be seen by this diagram that the meeting of the confluent waves along the face with those rolling in direct from the sea would set up a very severe action, and the blows on the concave surface at A would be so severe that nothing in the shape of a break-water could withstand it.

Moreover, the action of the waves would not only be severe on the break-water, but, as the confluent action would be diametrically opposed to the direct action of the waves rolling in at B, a very turbulent action of the waves would be set up, which would seriously affect the passage of a vessel into the entrance.

I have shown in red the modification I would propose for adoption in case an entrance at the elbow should be approved, the red arrows showing the action of the wave upon it, which would be far less intense than in the previous case. On the other hand, there is an undoubted objection to the modified form in that vessels entering and leaving the harbour would be thrown further into shoal water than in the form proposed ; but if this be an insuperable objection I am of opinion that the idea of an entrance at the elbow must be abandoned, for a concave face in such a position is in my opinion quite inadmissible.

There is another alternative entrance that might be worthy of consideration as offering shelter to the harbour without the objectionable features of either of the foregoing alternatives. This is shown in diagram No. 4 appended to this note, one of the faces being extended so as to cover the existing entrance, and, by demolishing part of the other face, a sufficient width for a free entrance may be obtained.

This would allow an entrance in deep water, and it is doubtful whether it would be more expensive than the plan proposed by the Madras Committee, for the portion E F would be equivalent to filling in the present entrance. The portion F G in diagram No. 4 would be equivalent to the portion D C in diagram No. 3; and the portion H K to be demolished would be somewhat shorter than the portion of the elbow which it is proposed to demolish for a new entrance. On the other hand, the portion F G in diagram No. 4 will be in deeper water than the equivalent portion D C in diagram No. 3.

If there should be a tendency to rapid shoaling to the south, it might be desirable to extend the other face so as to give the entrance to the north instead of to the south; but in this case the extension would have to be rather longer to give an equal cover to the entrance.
3-8-83. G. L. M.

It may be convenient to sum up my opinions on the four suggestions of the Home Committee as follows:—

1st.—I recommend that the raising of the faces and elbows of the harbour be accepted but that the raising of the sides be postponed pending further experience.

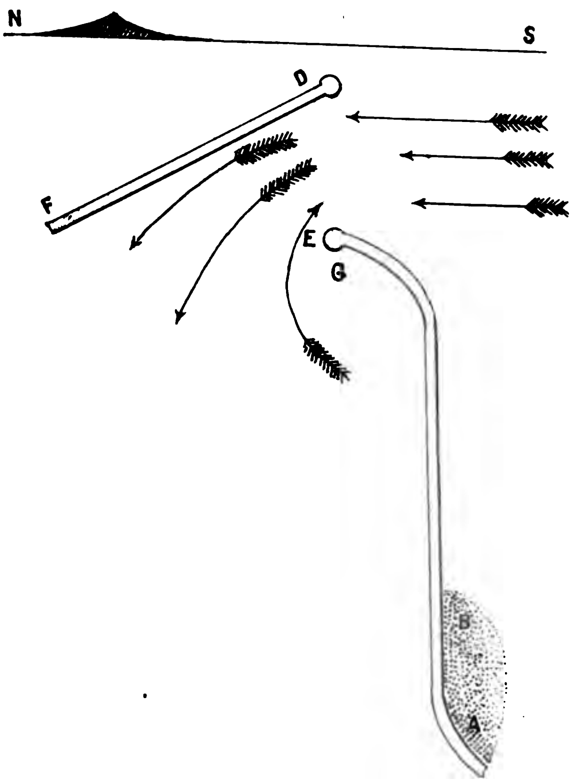
2nd.—I recommend that the wave-breaker for the sides be only carried out at first for two or three hundred feet from the elbows, and that its completion be also postponed until the necessity for it can be determined.

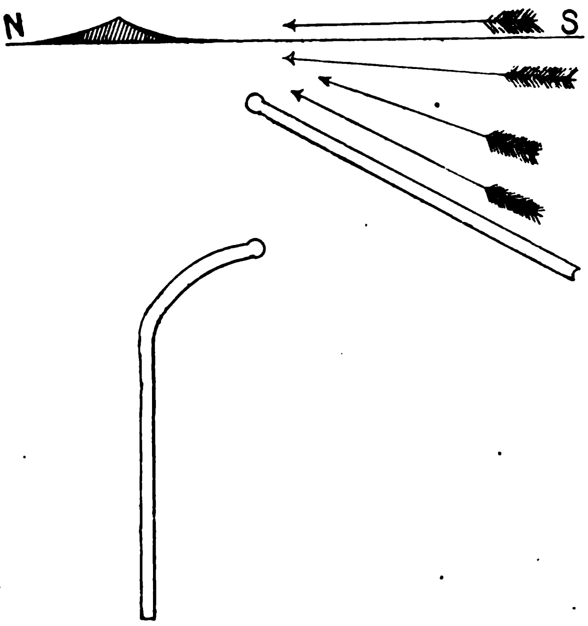
3rd.—I recommend the adoption of the random block system on the *débris* of the original wall, but I advise that the sections be modified in accordance with the typical sections given in diagrams 1 and 2 appended to this note.

4th.—I recommend a postponement of the reduction of the width of entrance until it can be ascertained by practical experiment with fixed beacons that such a reduction can be allowed with safety to the shipping; and with regard to the alternative entrance from one side, I advise that the question be referred to some eminent nautical authority in India, bearing in mind that a concave face to the break-water is quite inadmissible.

The settlement of the third point, namely, the method of reconstructing the face and elbows is the only one that presses for an immediate decision, and it is very desirable to arrive at a decision on this point with the least possible delay, not only to enable the manufacture of blocks to be recommenced, but also to prevent further disaster to the existing works from future cyclones by protecting them with random blocks.

Note by Colonel H. A. Brownlow, R. E., Inspector General of Irrigation, on the above note,—dated 2nd August 1883.





I detained this case, as explained verbally to Secretary and Mr. Molesworth, in order to obtain information regarding the strength, duration, and effect of the littoral currents. In respect to these see what Captain Taylor says in his letter of July 26th accompanying. Having regard to the greater duration and strength of the northerly current, and especially to what is stated regarding the great quantities of sand carried up from south to north by it, I most unhesitatingly advocate turning the mouth of the harbour to the north instead of the south. A current of 2 miles an hour moves 3 feet in a second, just the velocity of the Ganges Canal in its upper reaches, and I am very confident that, with a northerly current of that strength, a very awkward eddy would be generated at E* of sketch in the margin, if the harbour mouth is made to face the south.

* The current setting into the harbour along inner face of F D will tend to heap up the water within the enclosure and generate a current setting out at E. G.

This will be very much increased if the current should ever increase to 3 miles an hour, or 4½ feet a second, as it may easily do when the south-west monsoon is blowing strongly, and the danger to ships moving in and out would then be considerable. They could not hug the projecting face F D, as the current would be setting strongly on to it, and thus would be extremely likely to come to grief at E, as the steering would be very uncertain. Besides, when the sand, now being deposited at A B, moves up to the end of the projecting wall, a bar is sure to be formed at E. With the mouth opening to the north the sand would simply travel along the outer side of the projecting face, and would be constantly removed by the same action as that which now tends to cause erosion of the beach to the north of any projection from the beach.

Extract from letter from Captain J. H. Taylor, referred to in above note,—dated 26th July 1883.

The currents on the Madras coast are sustained by the monsoon winds and prevailing local winds.

2. Thus, in the latter half of March, when the local long shore winds blow, the current set to the northward steadily, and at a rate varying from ½ to 1½, or sometimes 2, according to the strength of the wind close inshore and as far out to sea as the observation of coasting vessels reach. This wind continues to blow in April and May, when it becomes merged in the south-

west monsoon wind which lasts till September. There is, therefore, a period annually of six and-a-half months during which a current runs to the northward. In October there is little or no current, but on the arrival of the north east monsoon in November a current from the north sets in and continues through December and January at about the same rate as the south-west monsoon current, ½ to 1½, or in extreme cases 2 miles per hour. February and part of March no current to be detected. The current from the north thus obtains for little more than three months as opposed to six and half from the opposite direction. The effect, therefore, is found to be that the sand with which the surf and sea near the shore is charged travels in great quantities from south to north, and is arrested by any projection from the shore and at once deposited while the clear water passing round the obstruction upon coming again into contact with the beach naturally takes up whatever sand it can find and thus causes erosion. Some partial restoration of this action goes on during the north-east monsoon, but the ultimate proportionate effect is as described. Examples of this are to be found at Covelong where there is a rocky spit, at the wreck of the *Southern Monarch* at Chepaok, the Madras Harbour Works, and at Pulicat and Armeghon. In the case of the harbour the action has already led to very great expense in protecting the north beach now, as there is no considerable rise and fall of tide to expose any mischief that is going on and no daily equal ebb and flow which might repair such mischief and the current being very searching and the sand easily moved, it follows in my opinion that there will always be danger to any work of the nature of an upright wall the value of which depends upon maintaining its equilibrium, whereas at Madras sand is the first and chief element of foundation. We have, in fact, one unequal tide throughout the year instead of two equal ones daily, as in England and elsewhere.

Further note by MR. MOLESWORTH on above,—dated 3rd August 1883.

I quite agree with Colonel Brownlow as to the desirability in this case of turning the opening to the north instead of the south, but I am of opinion that the northern entrance will require rather greater prolongation than that which has been shown for an opening for the entrance to the south.

Report of Committee appointed in G. O No. 1259W., dated 30th April 1883, and re-assembled under instructions conveyed in G. O. No. 2662W., dated 22nd September 1883, to consider the opinions expressed in the above.

The Committee re-assembled under G. O. No. 2662W, dated 22nd September 1883, to consider the notes received from the Government of India on their former report, have the honour to submit the following remarks.

2. The recommendations made by Mr. Molesworth are summarised as follows:—

" *First.*—I recommend that the raising of the faces and elbows of the harbour be accepted, but that the raising of the sides be postponed pending further experience.

" *Second.*—I recommend that the wave-breaker for the sides be only carried out at first for two or three hundred feet from the elbows, and that its completion be also postponed until the necessity for it can be determined.

" *Third.*—I recommend the adoption of the random block system on the débris of the original wall, but I advise that the sections be modified in accordance with the typical sections given in diagrams 1 and 2 appended to this note.

" *Fourth.*—I recommend a postponement of the reduction of the width of entrance until it can be ascertained by practical experiment with fixed beacons that such a reduction can be allowed with safety to the shipping; and with regard to the alternative entrance from one side, I advise that the question be referred to some eminent nautical authority in India, bearing in mind that a concave face to the break-water is quite inadmissible."

And an alternative proposal for covering the entrance to the harbour was made, which subsequently Mr. Molesworth amended in accordance with a suggestion by Colonel Brownlow.

3. Considering these recommendations in order, the Committee would only remark with reference to (1) that it appears to them no disadvantage that the sides of the harbour should be kept low, as the tops of the waves which would spill over into the harbour would be clear water which would mix with the otherwise stagnant water within the harbour and cause an outward flow to sea through the entrance.

4. With regard to (2) the Committee are satisfied that the wave-breaker is necessary to the whole of the north side. The circumstances of the north and south sides are very dissimilar, while the latter is comparatively sheltered during storms and is causing an accumulation of sand on the sea-side; the former is exposed to the first effort of the storm in the north-east

monsoon and is not protected by any outside bank. The necessity for some further outside protection is now apparent, for, although since the storm of November 1881, some 5,000 tons of large gneiss rubble have been tipped as foreshore, yet the centre joint continues to open, although the work has not been heavily attacked since the above date. Bearing this in mind the Committee would recommend the construction of the wave-breaker on the north side as one of the first things to be done.

5. In the Despatch of the Secretary of State which was communicated to the Committee with G. O. No. 1259W., dated 30th April 1883, it was stated that the views of the Home Committee should be accepted as closing the discussion on the principle of restoration to be followed; the Committee therefore framed their estimates according to the sections which were designed by the Home Committee. They would only remark with reference to (3) that experience has shown that the rubble base will not stand at a slope of 1 to 1.

6. As regards recommendation No. 4, the Committee feel very strongly that the northern entrance suggested by them is the only satisfactory arrangement. Attached to this report is a letter from the Master Attendant, forwarding the opinions of some of the commanders of the large steamers using the port, the best nautical opinions that can be obtained. It will be seen that all agree in considering the present entrance should be closed, and that the northern entrance proposed would be the best that could be designed.

7. It appears to the Committee that there can be no question regarding an entrance on the sea-face with a protecting arm to the south. Colonel Brownlow has adduced arguments against it which have been accepted by Mr. Molesworth, and which may be considered conclusive.

8. An entrance on the sea-face with a protecting arm to the north is, in the opinion of the Committee, open to serious objection, and is not to be compared with the proposed entrance at the north-east corner. In the first place the sea would still during the north-east monsoon set into the harbour and create a swell which one of the principal objects of the Committee's proposals is to avoid.

Secondly.—An entrance on the sea-face would curtail the deep-water space within the harbour which could be taken the fullest advantage of with a northern entrance.

Thirdly.—Such an entrance would involve the very difficult task of dismantling and removing the strongest and most deeply founded portion of the whole northern wall, whereas the entrance proposed by the Committee only entails the clearing away of that portion of the work that is already shaken to its very foundation and is now the most ruined part of the whole structure.

9. As regards the form of the protecting arm or horn, the Committee would observe that the slightly curved form proposed by them was adopted after due consideration, as will be seen by reference to their first report; and while allowing the objection raised by Mr. Molesworth to any re-entering angle on the face of the work, they consider that the arm might be made sufficiently strong to resist any action that may be expected. It would in fact be possible by increasing the block protection on the concave side of the curve to make the outward face an almost direct continuation of the face wall at no very serious additional cost.

10. The proposed shape of the protecting arm to the northern entrance given by Mr. Molesworth, would tend to force ships entering and leaving harbour into shoal water, and any such tendency is to be avoided, though during the north-east monsoon when there might be some difficulty in entering, it is to be noticed that the effect of the northern arm is to create an outward set from the shore to the extremity of the harbour, which would make the lee-shore less to be feared than it proverbially is.

11. The Committee are, however, willing to leave the question of the direction and shape of the projecting arm for future consideration, and would not object to some modification of the curve they have proposed. The construction of this arm will be the last part of the work to be done; the eastern entrance will have been closed and the northern entrance opened before it will be proceeded with, and the final settlement of the question may therefore, if desired, be postponed. The Committee, however, consider that the more nearly the entrance can be made to approximate to that proposed by them, the more satisfactory it will be found to ships using the harbour.

J. O. HASTED, *Colonel, R.E.*
J. H. TAYLOR, *Lieutenant, R.N.R.*
T. E. MARSHALL,
F. N. THOROWGOOD, *M.Inst.C.E.*
N. St. B. BEARDMORE.
C. BOWEN, *Major, R.E. Secretary.*

Extract paragraphs 1 to 5 from despatch from the Secretary of State for India, to the Government of India, forwarding a 2nd Report by the Home Committee on the proposed restoration of the Madras Harbour Works, - No. 23 P. W., dated 24th April 1884.

On receipt of Your Excellency's Public Works letter No. 59 of 13th November 1883, which forwarded a correspondence with the Madras Government relative to the engineering merits of the scheme proposed for the restoration of the Madras Harbour, I caused the subject to be again referred to the Select Committee who had been originally appointed to consider the subject, and requested that I might be furnished with their views on the modifications of the plan recommended in their report of 23rd January 1883, which had been suggested by the Committee appointed by the Government of Madras.

2. Sir John Hawkshaw has, in the accompanying report, furnished me with an expression of the joint opinion of himself and his colleagues on the recommendations of that Committee, and, after giving my careful consideration to the same in Council, I have come to the conclusion that the opinion now expressed must be accepted as the final decision on the questions raised.

3. The entrance to the harbour will accordingly be retained in its original position, and may be narrowed as recommended.

4. The side piers must be raised to the height of 12 feet above high water level, as originally recommended, and if loading places are provided in the manner suggested inside the harbour and near the piers, the necessity for raising them still higher will have to be considered.

5. With regard to the method of re-instating the work, Your Excellency will perceive that the Committee have not pronounced definitely in favour of any one of the three systems mentioned in their original report.

Second Report by the Home Committee on the proposed restoration of the Madras Harbour Works,—date London, 12th March 1884.

In obedience to instructions contained in a communication from the India Office, dated 6th of February last, copy of which is annexed, we have read and considered the papers forwarded to us, and have now the honour to report our opinions on the modifications suggested by the Madras Committee, of the plan we last year recommended.

The change suggested by the Madras Committee requiring the gravest consideration is their proposal to make a new entrance to the Harbour at its north eastern elbow and to stop up the existing entrance. Their object in making this proposal is to secure stiller water inside the Harbour, a thing desirable in itself if attainable with due regard to other considerations, and they state that the work remodelled in this and in other respects as they recommend will cost much the same as the works advised by us in our report of the 23rd January 1883.

The Madras Committee arrive at this conclusion of equality of cost by leaving out from their project the wave-breaker on the south side, and the concrete cap on both sides of the Harbour, and appear to have assumed, though we are at a loss to know why, that we did not attach any very indispensably constructive value to this portion of our recommendation. They seem to have looked at our proposal to raise the piers by a concrete capping mainly as a question of waves spilling over them into the Harbour, though the observation in our report was that raising the piers to the height we advised would add to the security of vessels within the Harbour in rough weather, and would greatly strengthen the work.

We cannot approve of further expensive works, the money for which is chiefly to be found by reducing the strength and efficiency of those recommended in our report of January 1883, which we now see no reason to abate.

It follows therefore, in our opinion, that the proposal to form a new entrance and to stop up the old one must be treated as an additional expenditure to that previously contemplated by us.

We have consequently estimated the cost of making the new entrance and of stopping up the old one; and taking the overlapping arm, as the Madras Committee show it, to be 600 feet along, which, in our opinion, would be the minimum length required, we make this additional cost to amount to £127,000. In considering the propriety of incurring such further expenditure, the following observations should be borne in mind.

The danger to vessels within the Harbour in a cyclone would arise from the winds as well as from the waves, probably more from the former than the latter, and we think that prudent commanders, on those occasions, would prefer getting out to sea to remaining inside the Harbour.

If the piers at the sides of the Harbour were left as low as is contemplated by the Madras Committee, they would in cyclones be nearly, and might be altogether, submerged, and vessels lying in the harbour would be floating in a receptacle brimful, or nearly so, of water, and

exposed on the north and south to the full force of the cyclone. In such case, with submerged piers, vessels breaking from their moorings would in all probability be lost.

Though the piers raised to the height we have recommended, while strengthening the work, would afford some additional protection from the wind, we do not assume that even then it would be safe to remain in harbour during a cyclone. Mr. Dalrymple, late Master Attendant, Madras, who has had lengthened experience of that coast, and who favoured us with his views on the occasion of our former enquiry, was of opinion that nothing short of 18 feet above high water would be high enough for the piers, and we consider the height of 12 feet, which we have recommended, to be quite low enough. Hereafter, in special cases, should vessels be required to lie at loading places inside the Harbour and near the piers, screens or walls, say 6 feet high, increasing the total height above high water to 18 feet, could be erected, and might prove necessary to give further protection from wind.

In large harbours it may almost be taken as an axiom that in proportion as you seek greater stillness inside you have to obtain it by rendering access to, and egress from, the harbour less easy.

On the occasion of our enquiry last year we were informed that a new entrance to the Harbour had been suggested at the south-east elbow, and we then considered the question of changing the entrance, and reported against it.

Though the Madras Committee say that the strongest winds are from the north-east, and though winds blow twice as long from that quarter as from the south-east, they now propose a new entrance fully open to those prevailing winds.

It is, perhaps, more a nautical than an engineering question, but we fear that access and egress through this new entrance would, in cyclones, be very difficult, the difficulty increasing just in proportion, as the entrance was made to face the north and diminishing as it faced easterly. Even with the north-easterly kant shown on the Madras Committee's plan, vessels could not make or leave the Harbour without being exposed to waves striking them on their beam, and tending to heel them over, or to carry them into shoal water on shore, or to cause them to strike against the end of the northern pier.

With regard to the new entrance there is another consideration of some moment. The present entrance could not be stopped up until the new entrance was made, and there would, therefore, for a considerable time be two entrances, and during that period there would necessarily be greater disturbance in the Harbour.

With regard to the methods of re-instating the work, the Madras Committee appear to prefer the random block system. This is shown in our report of 23rd January 1883, by Cross Section No. 5. Though we did not give it a preference, we stated in that report that it possessed advantages, and was a safe system to follow.

In framing that report we had to deal with a work which had been much more damaged in some places than in others, the extent of damage at some points not being very clearly ascertainable, nor capable of being determined until the work of restoration should be in progress; and hence we devised different methods of restoration.

Besides the objections we pointed out to the random block system, not perhaps very weighty in themselves, we were also influenced to some extent by difficulties of manipulation in that system.

On this subject we beg to remark generally that, referring to the three methods of reconstruction shown in our previous report, *viz.*—

1. According to Cross Sections 1, 2, and 3,
2. According to Cross Sections 1, 2, and 4,
3. According to Cross Sections 1, 2, and 5,

we consider that any of them may be adopted with safety, provided they are in no wise weakened by diminution of their dimensions or otherwise.

In considering the matters now referred to us we have had interviews with Mr. Parkes, who has explained to us his views. He sees some difficulty, as we did, in carrying out the system shown on Cross Section No. 5, and seems further to be of opinion that he should prefer to adopt Cross Sections 1, 2, and 4. With regard to this question, we think you may be guided by Mr. Parkes with the clear understanding, so far as we are concerned, that nothing is done to weaken any of the works recommended by us, whichever of the methods be adopted, and that the piers be not built to a lower level than we have already advised.

The only question remaining to be dealt with is the important one of change of entrance.

We have already pointed out that the change of entrance would add £127,000 to the cost of what we consider to be necessary works. We think also that in cyclones there would be difficulty in getting into and out of the Harbour through the proposed north-eastern entrance, and if during a cyclone captains were not disposed to remain in the Harbour, and could not

get their vessels out, it would be a serious matter. We have also mentioned that if a new entrance be formed, the Harbour will for some time be left with two openings instead of one, and will consequently be more disturbed.

We are still of opinion that the present entrance might with advantage be reduced to 450 feet, having walls vertical, or nearly so, on both sides of the entrance as we always contemplated, and see no reason to alter the opinion given in the last paragraph but one of our former report of the utility of the Harbour, if completed in accordance with our recommendations.

It must not be forgotten that whether the Harbour were completed with the present or with a new entrance, there are now no sufficient facilities within it for loading or unloading vessels; and if further expenditure is to be incurred, it is a question whether it would not be better to incur it in providing such facilities at or near the base or shore end of the Harbour rather than in making a new entrance.

After giving the fullest consideration to this question, we cannot recommend the construction of the proposed new entrance.

In conclusion, we beg to call attention to the fact that in all the estimates we have made, whether in this or our previous report, we dealt with our own prices in English money only, and our prices were in no wise modified or increased (as Mr. Parkes seems to have inferred), by adopting his rates and converting them into sterling money at the rate of two shillings to the rupee. The conversion of our estimates into rupees must, therefore, be made at the current value of the rupee, whatever that may be.

JOHN HAWKSHAW.
JOHN COODE.
G. G. STOKES.

Extract paragraphs 1 to 12 from a letter from COLONEL J SHAW-STEWART, R.E., Secretary to the Government of Madras, Public Works Department, to the Secretary to the Government of India, Public Works Department,—No. 2, dated Ootacamund, 9th June 1884.

I am directed to acknowledge the receipt of your letter dated 17th May 1884, No. 198M., with which is forwarded copy of a despatch and enclosures from Her Majesty's Secretary of State for India, respecting the proposed scheme for the restoration of the Madras Harbour, and in which you request that the Government of India may be favoured with an expression of the views of this Government in the matter.

2. The three points specially dealt with in the papers now under acknowledgment are—

(1) The position of the entrance to the harbour, together with its shape and width.
(2) The section to be given to the sea-face.
(3) The officer under whom, as chief executive authority, the restoration of the harbour is to be proceeded with.

3. With respect to the first point, I am to state that His Excellency the Governor in Council still remains strongly of opinion that the entrance should be placed at the north-east angle of the harbour, in from 7 to 7½ fathoms of water, as recommended by the Madras Committee; and that it should have a width of 500 feet.

4. As bearing on this point it appears to this Government that sufficient weight has not been attached to the unanimous opinions of nautical experts on the spot, copies of which were forwarded to you with my letter dated 11th October 1883, No. 2862 W. It is admitted by Sir John Hawkshaw's Committee that the question of access and egress through the proposed new entrance is "*more a nautical than an engineering question.*" That it is emphatically a nautical question scarcely admits of doubt; and on this point the nautical authorities who have been consulted are singularly unanimous. In a letter, dated 6th May, No. 4354, copy of which accompanies this, and to which special attention is solicited, the Master Attendant of Madras states: "All commanders of vessels who have been consulted, and that includes nearly all that have visited Madras since the accident, approve entirely the alteration from every point of nautical convenience." Captain Taylor adds: "I submitted some of the chief opinions, but could have collected hundreds, all giving testimony of the same nature."

5. I am directed to again solicit attention to those opinions; and, in doing so, to point to the fact that they represent the views of experienced men, commanding the largest steamers visiting the port—men who have known this coast and these seas for years, and who have watched the progress of the harbour works from the beginning. If there be any more competent nautical authority, thoroughly conversant with the somewhat complicated local conditions and with the nature of cyclonic storms, I am to state that His Excellency in Council earnestly requests that the question at issue may be referred to such authority before it is irrevocably decided.

6. In further connection with this point I am directed to observe that Sir John Hawkshaw's Committee appear to have misapprehended the circumstances from want of the necessary local knowledge. In paragraph 11 of their last report, they state that during 1883 they considered the question of forming a new entrance at the south-east elbow, and reported against it; and in paragraph 12 they continue: "Though the Madras Committee say that the strongest winds are from the north-east, and though winds blow twice as long from that quarter as from the south-east, they now propose a new entrance fully open to those prevailing winds;" the argument being apparently that, if a southern entrance cannot be entertained, *à fortiori* a northern entrance must be objected to still more strongly.

7. With advertence to this, I am to point out that the Madras Committee did not say the strongest winds were from the north-east, but "the heaviest seas yet observed have invariably been from the north and the north-east." As a matter of fact, the wind does not at Madras blow from the north and north-east for more than four months of the year, from October to February, the direction of the wind during the remaining eight months being more or less southerly. The direction of the wind, however, seems to have little effect on the swell, which rolls in with the crests of the waves parallel, or nearly so, to the coast line, with the result that seas enter the present mouth freely, and do not disperse before reaching the shore at the base of the harbour. Those seas would be deflected from a north-east entrance by the proposed protecting horn.

8. A further objection to the north-east entrance raised by Sir John Hawkshaw's Committee is (paragraph 14 of the report) that "there would, for a considerable time, be two entrances;" but I am directed to state that this Government do not attach much weight thereto, inasmuch as the old entrance could probably be closed and the new one opened, during the interval between two stormy seasons.

9. After most carefully considering all that has been urged against the proposed new entrance, His Excellency the Governor in Council adheres strongly to the opinion he has already recorded in favour of it. He considers that the retention of the eastern entrance will involve the loss of the greater part of the advantage which Madras might otherwise confidently expect to obtain from the harbour, and that it will also, in all probability, involve heavy and ever-recurring outlay to repair storm damages. And I am directed to add that this opinion is in no way contingent upon the decision that may be arrived at with respect to the necessity for providing the south arm of the harbour with a wave-breaker. If such provision can be dispensed with, as recommended by the Madras Committee, the new entrance can probably be opened within the sum (£480,000) named by Sir John Hawkshaw's Committee; but if otherwise, this Government are of opinion that the additional outlay, estimated by the same body at £127,000, *must* be incurred in view to the efficiency of the harbour and the security of vessels lying therein.

10. The question of whether ships could safely ride out a cyclone in the harbour may, in the opinion of this Government, be left to be decided by the commanders of such vessels. In most cases sufficient warning is given of the approach of a cyclone to enable vessels to get to sea, if they desire to do so; but it is impossible to entertain doubt that a vessel in the harbour would have a much better chance during a cyclone if the eastern entrance were closed than if it were open. It should, moreover, be remembered that the main object of the harbour is not to provide a refuge for vessels during the brief period of cyclonic storms, but to secure smooth water for landing and shipping operations in ordinary weather, and to protect the jetties and other appliances necessary thereto from the destructive effects of a cyclone to which they are liable so long as they are exposed to the direct influence of the sea from the east. Every convenience of this sort was wrecked in 1881; and unless the proposal to close the eastern entrance is accepted, it will be useless to attempt their reconstruction.

11. Respecting the proposal to reduce the width of the present eastern entrance to 450 feet, which is renewed by Sir John Hawkshaw's Committee in paragraph 22 of their late report, I am directed to observe that this too is more a nautical than an engineering question, and that the weight of local nautical opinion has been recorded strongly against the proposal. Upon this point I am to refer to paragraphs 25 to 27 of the Madras Committee's first report. With that opinion on record His Excellency the Governor in Council must continue to object to the proposal.

12. With respect to the second point dealt with in the papers under acknowledgment, namely, the section to be given to the sea-face of the harbour, I am directed to state that His Excellency the Governor in Council greatly prefers the third of the methods of reconstruction quoted by Sir John Hawkshaw's Committee in paragraph 18 of their last report, namely, the random block-work system. Its adoption was strongly recommended by the Madras Committee; and as Sir John Hawkshaw's Committee consider that it may be adopted with safety it is hoped by this Government that all objections will now be removed.

Note by G. L. MOLESWORTH, Esq., Consulting Engineer to the Government of India for State Railways,—dated 19th April 1884.

The joint report makes no allusion to the notes made by Colonel Brownlow and myself, and there is nothing in this report to induce me to modify the views I have expressed in my note of the 17th August 1883.

2. In that note I proposed a postponement of raising the sides until further experience had been gained as to the necessity for the work, and I still think that course should be pursued. Nothing would be lost and much might be gained by such a course of action, as the work of reconstruction of the faces and elbows is that which is the most pressing.

3. In the report it is stated—

> "The danger to vessels within the harbour in a cyclone would arise from the winds as well as the waves; probably more from the former than the latter: and we think that prudent commanders on those occasions would prefer getting out to sea to remaining in the harbour."

4. I entirely agree with this opinion; in fact, my views have been already indicated in my note as follows:—

> "I must confess that I am somewhat sceptical of the absolute safety of vessels in Madras Harbour during a cyclone, even under the conditions of having raised the face and elbows and closed the seaward entrance."

5. I may go still further and express my conviction that the capping would afford no protection against wind worth mention; and that even with this I consider it would be an act of madness for the commander of any vessel to remain in the harbour during a cyclone. If the capping and wave-breaker are to be added for wind protective purposes only, and not for constructive purposes, I think their construction will be a waste of money, as it is practically admitted that vessels cannot remain in the harbour during a cyclone.

6. The report also states that with the northern entrance proposed by the Madras Committee—

> "vessels could not make or leave the harbour without being exposed to waves striking them on the beam, and tending to heel them over, or to carry them into shoal water on shore, or to cause them to strike against the end of the northern pier.

7. This agrees with the opinion I have already expressed in my note in the following terms:—

> "When a vessel is entering such a harbour, half protected by the entrance and half exposed to the action of a heavy wave, it is liable to be swung round and strike the entrance before it can recover itself. This is a contingency to which modern vessels, from their extreme length, are specially liable."

The report, however, makes no allusion to the alternative I suggested in my note (as shown in diagram No. 4) with the view of meeting this difficulty.

9. The whole question, however, is, as the report suggests, "more a nautical than an engineering one," and I presume that the difficulty was considered by the nautical authority in the Madras Committee, and that it was preferred to face this difficulty rather than to incur the risk of narrowing the entrance. I would, therefore, repeat my previous recommendation on this point that—

> "with regard to the alternative entrance from one side, I would advise that the question be referred to some eminent nautical authority in India, bearing in mind that a *concave face to the break-water* is quite inadmissible."

10. No allusion has been made in the report to the suggestion I made in my note of a modification of the section originally proposed by the Home Committee, although I pointed out that this section was, in my opinion, open to the very serious objection of tending to break rather than to deflect the wave, and thus to set up a very destructive wave action.

11. We know so little of the possible ultimate force of cyclonic waves that I am very strongly of opinion that every endeavour should be made to *minimise the wave action on the structure*.

12. With regard to this question I annex some extract from the opinion of Mr. Scott Russel, the highest authority on wave action.

13. It will be seen from these extracts that the *breaking* of the wave is "a formidable thing to attempt," and that the limiting angle for *reflecting* a wave is 45° or a slope of 1 to 1; whilst the section proposed by the Home Committee has a slope greater than 1¼ to 1 for the blocks and nearly 4 to 1 for the rubble, which is clearly within the limits of wave action.

14. It is useless to argue that flat slopes have stood the effects of the waves at the English ports, for most of those ports are so land-locked that they are never exposed to any wave action at all approaching that of a *cyclonic* wave. They have, in fact, to deal with little more than the ordinary "oscillating" or surface waves, which, as the extract shows, are not the "deadliest enemies with which break-waters have to contend."

15. The Alderney break-water, which is more exposed than the majority of English break-waters, has been constructed with slopes of 2 to 1, changing to more than 4 to 1, and it has suffered severely.

16. The French engineers have acknowledged the soundness of the principles laid down by Mr. Scott Russel, and their more modern break-waters are constructed with slopes of 1 to 1 on the seaward face.

17. I am of opinion, therefore, that this slope should be adopted for the Madras break-water.

18. The report considers that Government "may be *guided by Mr. Parkes*" with references to the adoption of Cross Section No. 4; but it makes no allusion to the difficulty to which I have drawn attention in my previous note respecting the irregularity of the *débris* of the original wall which—

"being in advance of the new wall would probably set up a very serious wave action, of which it is impossible to predict the result."

and such an action ought, in my opinion, to be avoided.

19. The report, moreover, states that Mr. Parkes sees some difficulty in carrying out Cross Section No. 5 (random blocks); but, as it has not stated the precise character of that difficulty, I would suggest that its exact nature should be ascertained with the view of obtaining from Mr. Thorowgood a report as to the practical value of the objection, and whether this difficulty may not be overcome.

20. In conclusion, I may say that I adhere to all the recommendations I have previously made in my note of the 17th of August 1883.

Note by COLONEL W. S TREVOR, R. E., Secretary to Government of India, P. W. Dept.,—dated 21st April 1884.

It strikes me that the distinguished authors of the joint report are under a very serious misapprehension as to the character of a cyclone. They talk of vessels going into and coming out of the harbour during a cyclone, as if such a feat were easy of accomplishment with a sufficiently open entrance. As a matter of fact, it would be simply impossible for any vessel to make head against the wind and sea of these storms. If they wish to get out of the harbour to ride out the cyclone at sea, they must leave it at the first premonitory signs of its approach, which are generally unmistakeable. Once the storm has fairly set in, the ships then in the harbour must trust to their moorings and to them only for safety.

2. If the force of the waves rolling in from seaward be effectually broken by the break-waters, and the water in the harbour be no rougher than the wind acting on its limited area could make it, I for my part fail to see altogether what special risks ships attached to secure moorings, with their top hamper lowered, would run from the wind alone.

3. It has been my lot to be in two cyclones in Calcutta and one at sea. The first cyclone in Calcutta did immense damage to the shipping, owing entirely, in my opinion, to the defective moorings. Numbers of ships broke loose and drifted up and down the river till they were sunk by collisions with others or were finally lodged on the banks. A larger number still were sunk at their moorings, being cut down by the drifting vessels.

4. Before the second cyclone occurred the moorings had all been renewed, and though it was quite as severe as the first, the shipping scarcely suffered at all, though almost all the boats, as on the previous occasion, were destroyed. Wind alone won't sink a ship properly moored and in good trim, though heavy breakers without wind may. If then the breakers can be kept out of the harbour and proper moorings provided within it, every seaworthy ship should be able to ride out a cyclone in perfect safety.

5. What is wanted, therefore, for the Madras harbour is—

1st—A form of entrance which will not allow the heavy rollers from the bay access to the interior in any weather.

2nd—Sufficient height and strength of break-waters effectually to do the same.

3rd—Good moorings for the ships inside. If the entrance is also such that vessels may safely go in and out in ordinary monsoon weather, I do not see that anything more is either wanted or attainable. But to achieve so much, I would not shrink from expending £200,000 or £300,000 additional. Safe harbours are as much a want of the country as improved internal communications; and as the Government grudges nothing spent on the latter, it should equally little grudge expenditure on the former, which are practically only places for the transfer of goods from land to sea carriage, and *vice versâ*, *en route* to their ultimate destinations.

Enclosure to above note, being extract from remarks made by J. SCOTT RUSSEL, Esq., M. Inst. C. E., (Vol. XIX, page 653, 1860).

* * * * Now, in deep water, there were not only the *oscillating surface waves* to be encountered, but also those which he had termed *waves of translation*, forming what were called rollers at the Cape of Good Hope, and, when on a smaller scale, known as ground swell. These were a much more troublesome class of waves; it was mainly with them that the engineer had to deal in places open to the Atlantic: and after a storm of some duration at sea, they became the deadliest enemies, in the cases of deep water, against which break-waters for harbours of refuge had to contend * * * * *

To reflect or send back the roller was the most effectual plan. For this purpose, nothing more was necessary than a deep perpendicular face of perfect masonry, and so long as it stood firm it was faultless, and the water inside was smooth as in a mill-pond: for the reflection really converted the whole effect of the roller on itself into a simple pressure of water. When such a wave was reflected on a perpendicular wall, it merely produced a hydraulic pressure equal to that due to little more than double its own height. * * * * * An inclined wall, he had ascertained, would reflect a roller or deep wave nearly as well as a vertical wall down to an inclination of 45°. This observation was of value, because at 45° large blocks judiciously placed would not move out of position, even although a considerable breach was made in the wall near them. He had carefully watched the action of the sea when approaching this slope, and his opinion was favourable to the trial of a wall of heavy rubble blocks fairly laid, so as to form a tolerably even face or slope of 45°, when the nature of the materials and the local circumstances would permit.

When any approximative attempt at reflection of the wave, by walls not *too remote from the vertical*, had to be abandoned, recourse must generally be had to breaking the wave; *this was a formidable thing to attempt* on a deep-sea roller, and it could only be done by opposing mass to mass.

From LIEUTENANT J. H. TAYLOR, R.N.R., Master Attendant, Madras, to the Chief Secretary to Government, Madras, enclosing eight opinions from nautical men on the question of the entrance to the Madras Harbour,—No. 4354, dated Madras, 6th May 1884.

I must beg leave respectfully to apologise for addressing Government on a point of which I have no official knowledge, but the reports of which have reached me from sources that seem reliable. I hear that the restoration of the harbour of Madras is to be carried out with the omission of the one great alteration that will alone give any real value to it—I mean the closing of the eastern entrance.

2. Smooth water, upon which the whole comfort of the interior and the only chance of improvement in interior arrangements depend, will never be obtained, and Madras will be condemned to perpetual inferiority as a harbour, after so much will have been spent upon it. I would, with deep respect, but all the urgency that language can convey, implore His Excellency in Council not to accept such a conclusion until, at all events, the sense of the community has been sought, and its concurrence obtained. Every recurring storm, or presence of cyclone-wave in the neighbourhood of Madras, will repeat all the injuries that we witnessed on the occasion of the sea of November 1881. The sea that came through the east opening on that occasion destroyed the newly commenced low-level jetties, wrecked all the lighters, and committed general havoc on the beach among all classes of boats, before the walls showed any disposition to fall. His Excellency the Governor may perhaps remember that I waited upon him about 11 o'clock to report upon the weather, and that I reported the walls secure, but the damage above mentioned committed. It was on my return to the beach that I was an eye-witness of the very commencement of the work of destruction. The strongest portion of the walls, *i.e.*, each side of entrance of four blocks wide was the first to go, unmistakeably owing to the sea and current rushing round them and attacking on two faces at once. If this fearful blunder is not remedied now that an opportunity providentially offers itself, the last chance of a useful harbour for Madras is thrown away.

3. I know Mr. Thorowgood cordially endorses these opinions, though delicacy towards his Chief interferes with their expression; but no sentiment ought to be allowed to interfere where such enormous public interests are concerned.

4. I am also told that the east opening is adhered to from nautical reasons. This is entirely opposed to fact. All commanders of vessels who have been consulted, and that includes nearly all that have visited Madras since the accident, approve entirely the alteration from every point of nautical convenience. I submitted some of the chief opinions, but I could have collected hundreds, all giving testimony of the same nature.

5. The public are now committed to a tax upon the understanding that they will have a sufficient harbour; but I distinctly dare to assert they will never have one worth the name, or worth anything like the amount, unless smooth water is secured. Then all the conveniences of a harbour will soon follow, and few ports be in a better position than Madras. If no lesson is to be learnt from the destruction before us, correction for the fault will fall upon the innocent public, who, I respectfully submit, should be invited in some way to express an opinion upon a point of such vital importance to their future interests. The question is not one of engineering, where the judgment of such men as Sir John Hawkshaw, Sir John Coode, &c , is unassailable,

but is one of observation and experience in a perfectly novel situation. Observation convinces all who were witnesses of the former accident that the east opening is a fatal defect, and all experience teaches us that the sand on this coast is not to be depended on for a single season for the support of regular work like the upright wall.

6. Public feeling will, no doubt, be strongly excited when it is generally known that the anxiously expected harbour is only an unsatisfactory compromise, and that without any appreciable saving in money, they will be called upon to abandon the prospect they have had of docks, jetties, and countless advantages which the plan of the Madras Committee would have secured to the port.

7. I have marked this confidential, but of course that is only to secure the first consideration by Government. The facts will soon be patent and open to public controversy. I can write in officially if desired, and append the opinions of all my department.

From Lieutenant J. H. Taylor, R.N.R., Master Attendant, to the Acting Chief Secretary to Government, Madras,—No. 8607, dated Madras, 4th September 1883.

I have the honour to forward, as desired, the opinions of the nautical men upon the proposed closing of the east entrance of the harbour, and opening one to the north. The opinions are all strongly in favour of the plan, and are all by men of great experience and good position. I could, of course, continue the collection, but the result would be the same, while much valuable time would be wasted. There can be no doubt that the change would be good in every way, and the smooth water thus obtained, and the security offered by a wall, as recommended by the Madras Committee appointed in G. O., Public Works Department, No. 1259W., dated 30th April 1883, would be of incalculable advantage to the port, and admit of immediate beach improvements for landing and shipping.

From A. E. Barlow, Esq., Commander, P. and O. S.S. *Paramatta*, to the Master Attendant, Madras,—dated 1st August 1883.

I have read with much interest the reports of the Local and Home Committees on the reconstruction of the harbour of Madras, with which you were good enough to furnish me, having had considerable personal experience of the port for upwards of thirty years.

On the particular point upon which you wish for my opinion, namely, the closing of the present entrance to the harbour and the opening of one in the north-east angle of the north arm, so far from seeing any objection to it, I think it will be a positive advantage, as in my opinion it will be equally easy of ingress and egress with the present one, and will give a larger area of deep water for mooring large vessels, and will, I think, under all conditions render the water inside the harbour much smoother than it ever is at present. I return the reports, herewith, with many thanks.

From J. S. Murray, Esq., Commander of the P. and O. S.S. *Shannon*, to the Master Attendant, Madras,—dated 5th August 1883.

I have read with much interest the papers relating to the Madras Harbour, and having closely studied the plans, I have come to the conclusion that the plan proposed for its reconstruction by the Committee of June 1883 is the very best that can be undertaken, and that, while giving larger accommodation for shipping than ever before, it will ensure what was deficient in the old scheme, *viz.*, shelter and protection in cyclonic weather.

For obvious reasons the new entrance must be to the northward; and there can be no question about closing the present one.

I would venture to suggest that there should be no stint in the protecting arm for the new entrance, and that it should be carried out more northerly than westerly.

From W. A. Burkitt, Esq., Master, B.I.S.N. Co.'s S.S. *Dacca*, to the Master Attendant, Madras,—dated 10th August 1883.

I have looked over the plan for reconstructing the Madras Harbour, and think it an excellent idea closing up the present entrance, and having the new one at the north-east corner, and when the wall of the break-water is built higher, we ought to have perfectly smooth water. The harbour ought also to be able to give accommodation to several more steamers, and I don't see why it should not be able to give protection to ships in case of a cyclone; in fact, the present plan is the first which has caused me to believe in the utility of a Madras harbour.

From E. G. STEAD, Esq., Commander, S.S. *Kaiser-i-Hind*, to the Master Attendant, Madras,—dated 14th August 1883.

I have looked over the plans for the reconstruction of the Madras break-water, and most certainly think the closing up of the present entrance the very best that could be done, and the only plan by which smooth water can be looked for inside the harbour, which would then have greatly increased accommodation for more vessels, and with perfect safety.

The northern entrance would be quite as easy of ingress and egress, and to steamers preferring putting to sea on an approaching cyclone have perhaps less difficulty in getting out than through the present entrance, with possibly a gale of wind from north blowing full on her broadside.

From R. S. TURNER, Esq., Commander S.S. *Booldana*, to the Master Attendant, Madras,—dated 15th August 1883.

With reference to your request for my opinion regarding the proposed alteration in the Madras Harbour, I am of a most decided opinion that the only way in which smooth water and increased accommodation for shipping can be obtained is by closing the present entrance and making a new one at the outer end of the north pier. I cannot see why an entrance there should not, at all seasons, be as accessible as the present one.

The arm to protect the northern entrance, I think, should be curved *like* an arm towards the shore to protect the entrance from the north-east sea as much as possible, without interfering with the navigation.

My experience of the coast is twenty years in the British India Steam Navigation Company's service.

From J. DUFF, Esq., S.S. *Duke of Sutherland*, to the Master Attendant, Madras,—dated 1st September 1883.

With regard to the reconstruction of Madras Harbour, I beg to state that, in my opinion, to ensure despatch in working cargo, and also safety in cyclonic weather, it is absolutely necessary that the present entrance should be closed, and a new one opened; from local circumstances this must be at the north side, with a protecting arm. This would give room for more vessels, and if the break-water be raised, as proposed, give safety in a cyclone, vessels often being unfit to go to sea on short notice given.

From G. N. HECTOR, Esq., Master, S.S. *Carthage*, to the Master Attendant, Madras,—dated 4th September 1883.

I am obliged to you for a perusal of the plans now under consideration for the reconstruction of the Madras break-water.

The proposed alteration of the entrance from its present position to the north-east angle of the northern arm commends itself to my judgment.

The advantages gained by this change will, I think, be—

Smooth water inside the harbour.
Increased moving space.
Less liability to accident to vessels entering or leaving the harbour.
Probably less difficulty to vessels putting to sea in bad weather.

Despatch from the Secretary of State for India, to the Government of India, replying to certain objections to the proposed plan of restoring the Madras Harbour Works,—No. 56 P. W., dated 25th September 1884.

Your Excellency's Public Works letter No. 32, dated 4th July 1884, on the subject of the Madras Harbour Works, has received my consideration in Council.

2. Your Excellency forwards a communication addressed to you by the Government of Madras, together with a letter from the Chairman of the Madras Chamber of Commerce, reiterating objections to certain features in the plan of restoration of the harbour works as settled by the Committee to whom the matter had been specially referred in this country, and you state that you concur generally in the views held by the Madras Government.

3. It is recognized by every one that the chief objects which have to be kept in view in carrying out the works of restoration are, (1) the structural stability of the pier walls, (2) the selection of the best position for the entrance, in view to providing a safe and easy ingress and egress for ships, and (3) the security and accommodation to be given to shipping, especially local craft, by obtaining stiller water within the harbour.

4. It is to the position of the entrance to the harbour advocated by the Committee, and to its supposed unfavourable effect on the stillness of the water within, that the objections taken by local opinion appear to apply, and I have anxiously considered what course I should follow in consequence of this much to be regretted divergence of judgment.

5. The engineering questions discussed in the correspondence now forwarded to me have been so recently investigated a second time by Sir John Hawkshaw's Committee, the engineer members of which are regarded as among the greatest living authorities on works of the description in question, and who were in possession of, and carefully considered, all the views before expressed by the authorities at Madras and of your own professional advisers, to which I cannot find that any argument or statement of fact have now been added, that, without underrating the value of local knowledge and opinions, I have felt that it would be useless again to ask the Committee to reconsider their recommendations.

6. It appeared to me that, after consulting the best authorities available on the subject, no choice was left to me but to accept their decision on the question raised, the whole of which are of an eminently technical nature, and trustworthy opinions on which can only be formed upon prolonged and extensive experience such as that possessed by Sir John Hawkshaw and Sir J. Coode, and in my despatch No. 23 of 24th April last, I informed Your Excellency that this was the conclusion at which I had arrived, and I am not now able to see any sufficient reason for changing it.

7. In the accompanying report* which Mr. Parkes, in communication with Mr. Thorowgood, has made on the subject of future operations, he expresses concurrence with the conclusions of the Committee. He points out that the large vessels should have no difficulty in getting out to sea when a severe storm is threatened, and that of the approach of such storms timely warning can be, and in fact always has been, given, while, as regards the smaller craft, he is of opinion that the provision of floating docks or basins, which he shows might be formed on the land reclaimed on the south side of the harbour, would protect them from danger. Nor is it anticipated that, in ordinary weather, the quietude of the water within the harbour would be better secured by a change in the entrance. These suggestions are in conformity with the views expressed in the report of Sir John Hawkshaw's Committee, and, if acted upon judiciously, appear to offer a means by which to accomplish the object sought without changing the position of the entrance. Mr. Thorowgood, who is in full possession of Mr. Parkes' views, and of the reasons which have led him and the Committee to adhere to the eastern entrance, has already started on his return to Madras, and will be able to furnish the authorities there with any additional particulars they may require, and it is to be hoped that conflicting views may be reconciled by further discussion. Meanwhile, the plan of operations which Mr. Parkes has proposed will not preclude the further consideration of the position of the entrance of the harbour for several months at least, and possibly for another working season, and his plans should be followed generally, on the understanding that if any additional facts or arguments are adduced bearing on the question of the entrance which appear of sufficient weight to justify the step, a further reference to engineering authority in this country may become desirable.

* Dated 21st August 1884.

Two titan cranes.
One crane travelling wave-breaker.

8. In the meantime, the machinery noted in the margin has been ordered, and will be despatched to Madras.

9. With regard to the estimates which form the appendices to Mr. Parkes' letter, I beg that they may be examined, and that I may be duly informed whether they are such as may be accepted.

Report by W. Parkes, Esq., Chief Engineer, Madras Harbour Works,—dated 21st August 1884.

In the concluding paragraph of my letter to you, dated 5th July last, I stated that I was preparing a report, in which I proposed to deal with the various questions which have accumulated in the last two years, and which would include a more detailed explanation and estimate of the proposed works of restoration, together with a classified statement of the operations carried on, and the expenditure incurred during the period of the general suspension of work. I have now the honour to submit that report.

2. I will begin with the proposed works of restoration. The general character and extent of these works will be as laid down in the first joint report of the Committee, consisting of Sir John Hawkshaw, Sir John Coode, and Professor Stokes, dated 23rd January 1883, which I accept as my implied instructions. But the proposals I am about to submit are the result of a careful reconsideration of the existing state of the works, based on records of later date than those laid before the Committee above mentioned, and aided by personal conference with Mr. Thorowgood. The details of the new work have been independently designed, but where my conclusions differed from those of the Committee, I have carefully investigated the grounds of difference, and when I thought there was reason for doing so, I have not scrupled to increase the dimensions given by the Committee, and to introduce some additional precautions.

3. There are on the other hand one or two features of the Committee's plan of which I think it only right to state that I am not myself satisfied of the necessity, but I have included

these in my own design and estimate in deference to the opinion of the Committee. They are works for the execution of which no immediate provision can be made, and if I feel it my duty at some future time to raise the question of their being carried into execution, it will be in consequence of some definite confirmation of my present doubts.

4. On the accompanying general plan of the harbour, to a scale of 200 feet to an inch, the new works are shown in red, and on the sheet of cross-sections the character of the work at the different points is shown.

5. Commencing with the shore end of the north pier, and noting that the numbers represent the distance in feet from the point B, the first cross-section from 200 to 250 show the addition required to a special weak point. It is simply the continuation of a form of protection which was applied in 1877 as far as 200, and was so far very effective. There was at that time no occasion to carry it further, but the rubble foreshore has since been worn away by the action of the sea, and requires feeding and protection. This is shown, not only by the foreshore being rather bare in front of the wall, but also by the fact of the centre joint having latterly opened a little, which indicates a settlement. It will be seen by the section that the superstructure is only two blocks high at this part, so that it is founded at a depth at which the action of the sea is considerable, and a wide sloping foreshore is the only protection. Beyond the site of this special protection the superstructure is three blocks high, and founded at a lower level. The protective work consists of a rubble bank 50 feet long and 22 feet wide at the top, and tapered off at either end for a further length of 40 feet. On the top of this rubble 16 concrete blocks, each 9 feet × 9 feet × 6 feet, and weighing 30 tons, will be built during the ensuing three months, when the wind and sea may be expected to be invariably from the southward. The northerly seas of the next north-east monsoon will wash down the rubble bank, and the concrete blocks will drop and form a facing for the submerged foreshore, as was the case with similar work in 1877. As this work can be done with appliances now on the ground, as it is of importance to carry it out during the present season, and as it may fairly be considered included in the sanction already given for the protection of existing works, Mr. Beardmore has been instructed to proceed with it. Two thousand and five hundred tons of rubble and 288 cubic yards of concrete blocks will be required, and the cost will be about R7,500.

6. The above work will occupy the length from 160 to 290. In the remainder of the length, from 0 to 400, all that is required is to fill up the existing foreshore with a little additional rubble as may be required. This is in accordance with Section I of the Committee.

7. At 400 the line of continuous protection by random blocks will commence, but from 400 to 900 it will be of gradually increasing dimensions, from a single block laid against the foot of the wall at 400 to a mound, 20 feet wide at the level of high water at 900. Within this length the depth of water is such that any waves of sufficient height to be formidable will have been broken outside, and a wave-breaker, as such, is not required. All that is required is a protection against the scour of the foreshore.

8. At 900, where the depth at high water is 25 feet, and from thence outwards, the dimensions of the wave-breaker are intended to be such as to prevent the blow of the wave from falling with its maximum force on the superstructure. What these dimensions should be are not determinable, so far as I am aware, by any recognized rule, whether based on theory or experience. It is a matter in which each engineer must use his own judgment, and mine, based on the best data I am acquainted with, would give rather greater dimensions than those shown by the Committee. The difference so far as cost is concerned is not very great. If the additions were made by increasing the quantity of concrete blocks, the increase of cost would be about a lakh and a half, but if made (as I think may be done without any infringement of the essential principles laid down by the Committee) by forming the interior of the mound of large rubble, the increase of cost would be only half a lakh. I think I am justified in asking the Government to sanction this modification of the design, so that it may cover my own conceptions of the required conditions of stability, but I shall, of course, be prepared to submit my conclusions to further consideration if it is considered desirable to do so.

9. It will be understood then that the following dimensions for the wave-breaker are rather in excess of those shown by the Committee, but the excess is obtained by forming a nucleus of large rubble against the face of the wall and covering it with blocks. This large rubble will be deposited immediately before the blocks, so that it may not be exposed to the wash of the sea before being covered with blocks.

10. At 900 feet, then, as before said, the width of wave-breaker at high water (taken as one foot above De Haviland's mean sea-level) will be 20 feet, and the width will gradually increase to 28 feet at 2,200 (see sections at these points). The blocks will be allowed to form their own slope to seaward, each block being simply carried out by the wave-breaker crane to the required distance and dropped into the sea, till the mound has reached the required height,

If future storms should draw the mound down to a flatter slope, more blocks will have to be added to maintain the designed width at high-water level. The slope of 1½ to 1 shown on the sections is that at which it is anticipated the mound will be ultimately permanent in form, but this, of course, cannot be guaranteed.

11. The point 2,200 is the limit to which the existing work can be utilised as a built structure. Since the storm of November 1881 the upper blocks have been tied together with pieces of bent railway bars cemented into them, and the top has been levelled with concrete. Nothing more will be done till, as a final operation, after the whole length of the piers shall have been completed, the capping of concrete, in mass about six feet high, recommended by the Committee is placed upon it.

12. From this point forwards the system of construction will be in a certain sense reversed. Instead of placing a new wave-breaker in front of the old work, the old work will be treated as part of the wave-breaker, and a new wall constructed inside it. By this arrangement the old work will be utilised to the fullest extent, while in the execution of the new work the elements of uncertainty will be reduced to a minimum. It will be a continuance of the system of work hitherto carried on with much success as an executive operation, and of which the cost is well known. Some modifications and some special works, however, will have to be introduced, which to a small extent will involve new conditions.

13. The mode of passing from one system to the other is shown upon the plan. The old building is standing complete to 2,200, and from that point the new building will commence as a complete section, but in order to form a continuous line along which the setting machines and the blocks and other materials can pass without interruption, it is proposed to build a wall 12 feet wide for a length of 160 feet back, starting at 2,040. This wall will curve away from the old wall (the space between the two being filled in with rubble and concrete) till sufficient space is gained to build the section to the full width of 24 feet.

14. The new building will be of the same general character and dimensions as its predecessor, but there will be some modifications of detail. The original building consisted of two independent walls placed in contact, but not tied together. It is recommended that for the future the blocks should be bonded together, so as to form one wall, and in this recommendasion I concur. The unbonded system has great advantages in comparatively shallow water, in which the waves have little effect on the blocks themselves, but much on the foundations, while in deeper water the action of the sea on the foundations is less, but that on the blocks themselves is greater, and this fact turns the scale in favour of bond for the outer portions of the piers. At the same time the bond rather increases in some respects the difficulties inseparable from a compressible foundation, and new difficulties are introduced by the special circumstances of the case.

15. It will be seen from the sections that the new rubble base will be deposited over the inner slope of the old, and upon that slope some of the overthrown blocks are lying. All the blocks which lie under the line of the new building will have to be removed, either bodily or by blasting, for if they are allowed to remain, they will cause inequalities in the settlement, which will be highly injurious to the superstructure above. In order to avoid these blocks as much as possible, I have increased the distance at which the Committee proposed to place the new pier from the old one by 9 feet, and this will also place the line of new building more clear of the old rubble.

16. But even with these precautions of removing the old blocks, and increasing the distance from the old work, there will still be a greater liability than there was in the original work to unequal settlement. The sea-side of the new building will still partially rest on the old rubble, which has been consolidated by four or five years' exposure to the sea. The new rubble will be in the same position as the old was when first built upon, that is, it will be liable to be compressed to the extent of a foot or 18 inches within a few hours after the weight of the blocks is placed upon it, and to a slower settlement subsequently extending over months, and perhaps years. This latter slow process of settlement, however, is not injurious to the work. But the first is so; it subjects the blocks to great and irregular strains, and is, I think, the most fruitful cause of many of the original blocks having been broken. The evils would be materially aggravated by the fact of one side being more liable to settlement than the other.

17. It is, however, possible materially to reduce these evils, if not to prevent them altogether, and it is proposed to do this by subjecting each length of bed after it is prepared by the divers, and before the blocks are set to a compression rather greater than that of the blocks themselves. This will be accomplished by placing in front of the work a pile of iron (old rails, with the interstices filled up with cheap cast-iron bars), covering the same area as a row of blocks, and having a weight rather greater than that of the blocks. This "compressor" will

be moved forward in advance of the building by the titan. If, after its removal, it is found to have compressed a bed unequally, the hollow parts will be fitted up with suitable flat pieces of stone before the blocks are set.

18. I propose to introduce another departure from the original design, which will also diminish the evils of settlement. In the original work the foundation blocks were 6 feet high, and above this there were three courses of blocks, each 8 feet high, the whole being 4½ feet wide. It is intended now to use blocks 6 feet high and 6 feet wide, of which there will be five courses, including the foundation course. These blocks will be stronger than those 4½ feet wide, and less liable to break. There is also the incidental advantage that the iron compressors would have to be advanced in stages of 6 feet instead of 4½ feet, and this would accord better with a fair rate of progress of one row per day.

19. It will be seen by the cross sections that the foundation course consists of two blocks of equal length (each 14 feet), the upper courses of blocks of 14 and 10 feet alternately breaking joint. Thus, the foundation course will not be bonded. The reason for this is that there would be a practical difficulty in manipulating both the 16 feet and the 12 feet blocks in that situation. I pointed out these difficulties to the Committee, and obtained their concurrence to this small departure from their recommendation. The importance of bonding is greatest in the top course, and diminishes in descending. In the bottom course it is practically *nil*.

20. The blocks will be further locked together by means of a projection on the top of one block fitting into a corresponding recess in the bottom of the block above. This principle was adopted in the original work, and was certainly successful in preventing the blocks from sliding on one another, as they had been found to do at Kurrachee and elsewhere. In the present case a connection of a similar kind will be made between the ends of the 14 feet blocks on one side with the ends of the 14 feet blocks in the courses about and below on the other side, which overlap them, and there will also be hollows and projections on a somewhat similar principle in the backs and faces of the two top courses, thus giving additional ties throughout the whole width. A further tie will be given by means of a bent rail cemented into the two blocks of the top course in every row, but the cramp which is shown in the Committee's sections in the second course from the top may, I think, be dispensed with, in consideration of the additional ties provided by the projections and hollows in the blocks themselves. The cramp could be only very imperfectly fixed, as it would be constantly in the wash of the sea, and the necessity of fixing it before setting the top course would be a serious obstruction to the work.

21. There will be an interval of about 45 feet between the face of the new wall and the back of the old one, and in this space the great bulk of the overthrown blocks are lying. The remainder of the space will be filled up with random blocks to form the wave-breaker, of which the remains of the old work will form the sea slope. Any of the old blocks of the two upper courses that remain in place will be removed to the body of the wave-breaker so as to leave the sea-face fairly uniform. The two lower courses of the sea-wall at any rate are very nearly perfect, and will form a continuous toe to the slope of the wave-breaker very much as shown in the average section from 2,600 to 3,800.

22. There are now in stock 800 blocks which will be available for use in the wave-breaker. They are not of the best form for the purpose, but they will be used in the under-parts where this is not of consequence. About 6,000 additional blocks will be required to complete the wave-breakers, and there will be uniformly 9 feet × 9 feet × 6 feet, and weigh 30 tons each.

23. The same system of work will be continued to the pier head, but the new built work will be curved round as shown on the plan, so as to avoid a great mass of fallen blocks among which the "titan" is lying embedded, and also to obtain an entirely new foundation for the additional 50 feet of length required to obtain the narrower entrance. The old pier head is standing with the lower courses almost perfect, the interval between the ends of the old and the new work will be built up with a solid wall of concrete blocks, and the enclosed space behind filled in with random blocks. The last 200 feet of the new pier, including the portion facing the entrance, will be made 38 feet wide, instead of 24 feet, and will be founded 12 feet lower than that within the harbour, or 34 feet below mean sea-level. Its toe will be protected by an apron of concrete blocks laid on the foreshore.

24. The work at the south pier will be generally similar to that at the north, except that, in consequence of the advance of sand, the protection works need not be commenced so near the shore, and there is no place requiring special protection like that proposed for from 200 to 250 at the north pier. There has been some advance of the sand since the date of the latest survey (1882), and in execution rather less work will be required than is shown upon the accompanying plan and sections, but for the present I have thought it better to base my estimates on the latest complete survey.

25. According to this then the protection by concrete blocks will commence at 1,000, and will gradually increase up to a high-water width of 20 feet at 1,300, where the depth at high water is 25 feet. It then continues with the width gradually increasing to 28 feet at 2,550, up to which point the existing pier is perfect.

26. At 2,550 the new pier commences, being connected with the existing work in the same manner as at the north pier, and is carried on to the head with only such variations as the different circumstances require. The line shown on the plan passes between the overthrown blocks and the titan. The titan is not in this case encumbered with blocks, and can be removed by blasting if it should be necessary to do so. The new head will be connected with the old one in the same manner as at the north pier. The difference in the form of the two heads is rendered necessary by the different positions of the fallen titans, but there is no objection to it, as it will be scarcely noticeable from any accessible point of view.

27. I estimate that the above works will require 3½ years from the re-commencement of block-setting in June next, or till about the end of 1888. The estimated cost is R45,90,051, including 7½ per cent. for establishment, and 2½ for contingencies, but this estimate does not give a basis for determining the total cost of the harbour as completely restored, without taking into account the expenditure since the storm of November 1881, and the relation of that expenditure to the previous outlay on the one hand, and to the future outlay on the other, I shall show (in para. 42 *post*) that a sum of R2,96,334 has been already expended on works and materials included in this estimate.

28. The total expenditure up to 31st October 1881 was R58,72,082, including R1,53,945 expended in the purchase and partial fixing of moorings which were the subject of a different sanction from that of the harbour works proper. It also included the value of certain materials which had been acquired for the completion of the work and are still available.

29. Between 31st October 1881 and 30th April 1884, R9,08,088 have been expended, and regular monthly statements, purporting to account for the details of this expenditure, have been regularly submitted to Government, but as, in conformity with the inflexible rule of the Public Works Department system, all charges are referred to heads for which there is a corresponding sanctioned estimate, the accounts would show that expenditure has gone on increasing for works to which no addition has been made. It is obvious that the present form of the accounts can only be viewed as provisional, and that any real explanation of the expenditure must be based on an entire re-arrangement of the statement.

30. At my request Mr. Thorowgood has made such a re-arrangement, of which I append a copy (Appendix A). From this it would appear that the total expenditure may be classed as follows:—

	R
1. Actual work, and purchase of materials for work	4,43,972
2. Purchase of land threatened with erosion, and compensation for land washed away	2,58,075
3. Establishment, and salaries of foremen under agreement	2,06,041
	9,08,088

But as the first and second of these items were incurred under the superintendence of the harbour works' staff, they should bear their fair charge for the cost of such, which I place at 10 per cent. for the first, and the sum of R6,650 (the actual salaries of the persons employed) for the second. With these corrections the items would stand thus—

	R
1. Actual work, &c.	4,88,369
2. Purchase of land, &c.	2,64,725
3. Establishment. Cost during suspension of work	1,54,994
	9,08,088

31. Now, I would submit that the last two of these items, although fairly debitable to the harbour *undertaking*, are not fairly chargeable to the *works*, and should be kept distinct in any statement of expenditure. I shall have occasion further on to explain the circumstances under which the outlay under the second head was incurred, and I will only now say that it ought to appear in a statement of gain and loss of land, in which there is a credit as well as a debit side. With regard to the third, I need only say that to add it to the item of "Establishment" in the accounts of either the old or the new works could only mislead. I submit that it should appear as an item by itself.

32. There remains to be accounted for the sum of R4,43,972, or, including cost of management, R4,88,369, little more than half the total of the official statement. This may be classed under four heads, as under—

	R
A. Stone revetment for protection of shore north of harbour	1,13,618
B. Expenditure debitable to the original design	1,17,769
C. Expenditure consequent on the storm of November 1881	39,509
D. Expenditure in anticipation of the restoration works	1,73,076
	4,43,972

33. The first of these items is part of a total of R2,04,627 expended on this object, and hitherto charged to "Contingencies." I think it might fairly be placed in the same category as the purchase of land, for which it is simply an alternative, but, at any rate, it should be kept apart as an exceptional item of expenditure.

34. Item B consists of R75,029 expended on levelling and clamping the injured portions of the piers, and this would have been done even if the remaining portions of the work had not been damaged by the storm; R15,328 is the expenditure on moorings in the month of November 1881, previous to the storm. The remainder of this item, R27,412 covers R16,013 expended on an extension of the town sewer at a spot more than half a mile from the harbour, and chargeable to the harbour funds on rather questionable grounds. This leaves R11,399 for various small contingent expenses.

35. Item C consists of R16,485 expended in clearing away the wrecks of the two hopper barges sunk in the storm, and this has to be reduced by more than half of a sum of R12,835 (the proceeds of a sale of the recovered materials of the barges and some other old materials not easily separable); 17,803 expended on the recovery, removal, painting, and tarring and stowing away for future use of mooring materials; and R5,221, repairs to private property damaged in the storm.

36. Item D consists of R87,230 for new concrete blocks, R58,079 for various repairs and renewals of plant and machinery, and R27,767, the net increase in the value of unissued stores and materials since November 1881. The expenditure under this item (D) are charges against the estimate for the restoration works.

37. I have appended (Appendix B) a statement of the total expenditure from the commencement of the works to 30th April last, classified under five principal heads, which I would submit for adoption in future accounts. The following is a summary :—

Sanctioned Estimate.	Name of Account.	Expenditure.
R		R
56,50,000 . .	I. Original design	56,57,840
2,00,000 . .	II. Moorings	1,90,589
	III. Cost of establishment during suspension of works .	1,54,994
	IV. Gain and loss of land	4,82,114
	V. Restoration works	2,96,334
	Total as per official return . .	67,81,871

38. The first of these, I would suggest, may be considered a *closed account.* The official statement of expenditure up to 31st October 1881 has been amended by the addition of such subsequent works as are fairly debitable to the design, and by the removal from it of charges which must still be kept open, some being transferred, as shown in the Appendix to Account IV, and some to Account V.

39. The second (moorings) must be kept open, but no further expenditure will be incurred till the restoration works are further advanced. An amended estimate, though not a very large one, will then have to be submitted.

40. The third (cost of establishment during suspension of works) I would suggest should be treated as a *closed account.* A liberal allowance has been made for the legitimate cost of superintendence of such works as have been going on during the general suspension, and the sum of R1,54,994 is the remainder.

41. The fourth (gain and loss of land) I shall explain more fully further on, and show that it should be treated from henceforth as one side of a Dr. and Cr. account.

42. The fifth will be absorbed in the regular accounts of expenditure on the restoration works, and will appear under the proper heads. Sanction is asked for an estimate of R45,90,051, against which this amount of R2,96,332 will be the first charge. The estimate itself, in the form which I submit for adoption, is given in Appendix C.

43. I beg now to return to the subject abovenamed, the gain and loss of land. This subject has been treated in former reports as the "sand difficulty" and the "changes of the coast line," but the two latter descriptions are now imperfectly applicable to it, while the first represents the result which is now most prominent.

44. It will be remembered that from the commencement of the works it became manifest that there were movements of sand up and down the coast in opposite directions in the two monsoons, of which the movement from south to north during the south-west monsoon was the greater. This movement being obstructed by the harbour piers, the result was an annual advance of the shore line on the south of the harbour, and an annual retreat of the same on the north. The plans show the former in its successive steps for the last seven years. Each blue line shows the most shoreward position of high-water mark for the year. It advances every year from about March to about October, and then retreats from October to March. The rate of increment decreases with fair regularity from year to year, as the length of shore to be covered and the depth of water to be filled increase. It is clear, on the one hand, that there is no indication of a limit to the advance, and on the other that, considering the decreasing ratio in the rate of advance, the time when it will be injurious to the harbour is still very remote. The area of land gained from the sea up to the present time is 70 acres.

45. Within the harbour there has also been an advance of the shore line, but this took place almost entirely during the years 1876 and 1877, when the north pier formed the only barrier to the northerly movement, the south pier not having then advanced sufficiently to arrest it. Since the latter year there have been some variations in the positions of the high-water line, due to local causes, but no persistent annual advance. The area of land gained within the harbour is 18 acres.

46. To the north of the harbour the result is, as might be anticipated, the reverse of that to the south. The preponderating northerly movement of sand causes an annual erosion instead of an accumulation. But the progress is much less regular. This is due to two causes, the one natural, the other artificial. The natural cause is this. The sand within the influence of the waves is subject to two distinct movements,—the alongshore movement due to the oblique stroke of the wave (and this is greatest in moderate weather), the other a transverse movement which is *on* or *off* shore according as the wind is *off* or *on* shore. Thus, the *off* shore wind in itself accumulative all along the coast acts with an accumulative alongshore movement to the south, and an erosive movement to the north, and the *on* shore wind of the remainder of the year, erosive all along the coast, acts with the erosive alongshore movement to the south, and the accumulative to the north. Hence the forces are in both seasons acting in concert to the south, and in opposition to the north, and the result is much greater irregularity in the annual changes where they are in opposition.

47. The artificial cause of irregularity is that whenever erosion is manifested, protective measures are naturally at once taken, and these counteract the local erosion, even if they drive it to some other locality. As a whole, however, the protective measures appear to have been efficient, for while the gain of land to the south of the harbour has been, as already stated, 70 acres, the loss to the north has been only 41 acres, and this is, of course, entirely beyond the limit of the protective works.

48. For the above reasons the conclusions to be drawn from the records of erosion north of the harbour are much less definite than those drawn from the records of the accumulation to the south. We know that erosion is going on, but both the rate of it and the locality for the future are very uncertain. Nevertheless, I think a provisional settlement has now been made upon a tolerably satisfactory basis, and I would ask for a confirmation of it.

49. To explain the present state of the question I must go back to the early stages of the work. The part of the shore affected extends for about two miles northward from the north pier. For three-quarters of a mile there was a made road along the shore, and on the landward side of this road stand in succession the Madras Railway Company's Royapooram terminus and offices, the Biden Seaman's Home (these are shown on the plan), some merchant's godowns, a first class bungalow and compound belonging to the late Honourable J. G. Coleman (lately purchased by the Government), and a cluster of small brick-built native houses. Beyond this, there was no regular road, but the shore was occupied by hut villages, with few permanent buildings and timber yards. A little inland are five second-class bungalows standing in compounds having a depth of some 400 feet, beyond which is a good road parallel with the shore. To the northward of the last of these bungalows is a native village with a bazar, but few permanent buildings, and beyond this, agricultural land.

50. As the north pier advanced into the sea in 1876 the first effects of erosion were felt opposite the railway terminus. These were immediately met by the deposit of stone and bags of concrete, and little inconvenience resulted. As the pier advanced further seaward, the local-

ity of erosion was thrown further to the northward, and the protective works assumed the form of a continuous stone revetment between the road and the sea, and upon this had been expended up to 31st October 1881 the sum of R91,009. It extended to a point 3,450 feet from the north pier, and little beyond Mr. Coleman's property.

51. The storm of November 1881 showed, as had been anticipated, that this revetment required an addition of stone, as the first was worked into the sand by the action of the sea. Some of the buildings close to the road were damaged, and were repaired at the expense of the harbour works, but, on the whole, the results of the storm were not serious so far as the revetment extended.

52. But the question was now prominently presented. How far is this protective revetment to be carried? It was effective as far as it went, but costly, and it became evident that it would be possible to spend more in protecting the land than the land itself was worth. In the early part of 1882, therefore, while at Madras, I investigated this question, and satisfied myself that, though the revetment was fully justifiable as far as it had gone, for up to that point the evil of erosion would be even greater than the loss of the value of the land, this would not be the case much further on. I therefore recommended that the existing revetment should be strengthened, and that it should be extended northwards sufficiently to make a fair junction with the new line of shore, but that beyond that no further protection should be attempted. All the land abutting on the shore for some two miles northward should be purchased by Government, so that no further questions of compensation to private owners should arise.

53. These recommendations have since been carried out. The revetment has been completed and extended at a cost of R1,13,618, and 140 acres of land have been purchased, or its loss compensated for, at a cost of R2,59,475, and these sums, together with the R91,009 spent on the original revetment, and the cost of management, make up the sum of R4,82,114 which I put forward in paragraph 37 as the *debit* side of the "Gain and Loss of Land Account."

54. I have now to show on what the credit side of this account will be based, and while I allow that the great bulk of this is still in the future, yet I submit that the longer the opening of the account is delayed the greater will be the difficulty in establishing it.

55. I have mentioned that 140 acres of land were purchased; of these 41 have been washed away, so that 99 acres remain. The rents of these are collected, and under present orders are to be credited to the harbour works funds. These at any rate should be placed in the new account.

56. Then there have been gained within the harbour limits, as stated in paragraph 45, 18 acres of land. A great part of this has been utilized, and two large godowns have been erected upon it by the Marine Department for port revenue purposes. The value of the accommodation thus given should be credited to the same account, either by the land being transferred to the Marine Department at its fair value, or by an annual payment proportioned to the use made of the land. This payment would no doubt increase from year to year.

57. To the south of the harbour 70 acres have been gained. The Commissariat Department have appropriated an advantageous site, which, five years ago, was in the surf, on which a building, 200 feet by 120 feet, has been erected. Another site has been appropriated in a similar manner by the Marine Department, on which was erected a shed for horses landed from ships. Other buildings of the same kind will no doubt follow, for the situation is a valuable one, and though it is no doubt gratifying to see it utilized, it is somewhat inconsistent that the outlay by which it has been acquired should be debited to one Department, and the returns credited to another.

58. The above are Government appropriations, but private individuals are also profiting by the new site. The dealers whose timber yards north of the harbour were purchased at a high price out of harbour works funds are occupying the new beach south of the harbour for the same purpose *rent-free*, or if rent is paid, it is not credited to the harbour works accounts.

59. I am well aware that if revenue were collected from the sources I have indicated, it would make at present but a small show in comparison with the expenditure, but it is certain that it would increase, and it is also desirable that the new land should be recognized as a property which has been acquired by the Government, at a cost of nearly five lakhs of rupees, and that some control should be exercised over its occupation. I would add that I am about to point out a mode of utilization of a portion of a site which would ultimately add materially to the value of the whole.

60. I would now beg to submit some remarks on the future utilization of the harbour, which, although they can only be followed up by definite recommendations for immediate action to a small extent, are, I think, especially called for at the present time, because the

subject has been lately under discussion from another point of view. A proposal had been made to alter the position of the entrance, with the view of obtaining stiller water in the harbour, but as this proposal was not approved by Sir John Hawkshaw, Sir John Coode, and Professor Stokes, on reference to them by the Secretary of State, it may now be considered at an end. It is only necessary for me to say that I concur in their conclusion, and I only refer to it now as giving a suitable occasion for pointing out what may be done for improving the accommodation of the harbour with the entrance in its present position.

61. The main points to be kept in view are—

I—The safety of ships.

II—The facility for loading and discharging cargo boats alongside the ships.

III—The facility for loading and discharging cargo boats at the shore.

IV—The safety of cargo boats and other local craft in bad weather.

62. With regard to the safety of ships, I think it is now generally understood, though it may be somewhat inconsistent with the popular ideas upon the subject, that a harbour may be very useful, even though it may not be a place of absolute safety in the heaviest storms. If Madras were a terminal port, such as London or Liverpool, or even Calcutta or Bombay, the want of absolute safety would be a serious drawback, but Madras is essentially a port of call, where ships only remain for a day or two, and are never dismantled. A steamer's fires are never let out during her stay in the port, and no sailing ship would ever be admitted, unless in very settled weather, without every facility being provided for her leaving at an hour's notice, and in any wind. To be caught in a cyclone at Madras, therefore, is no more than to be caught in a cyclone in mid-ocean, provided always that the ship can get to sea. This then is the provision that is wanted, and not a safe mooring in the height of the storm.

63. Now it must be remembered that the dangerous storms in the Bay of Bengal never come without notice, but occasionally, indeed frequently, the notice comes without the storm following. This is a source of inconvenience, because precautions have to be taken upon the *notice*, before the actual advent of the storm, when they would be too late. Hence it happens more often than not that when ships are sent to sea they return without having met with the expected storm.

64. But this is an inconvenience which may fairly be expected to be lessened as the indications of storms are better recorded, and the actual courses of existing storms are more perfectly traced. Even as it is, however, the inconvenience is not an intolerable one, and may be taken as an infinitesimally small deduction from the real value of the harbour. During the last two years there have not been more than four or five occasions on which ships have been warned to sea, and not one on which they would have been in actual danger if they had remained at their moorings in the harbour, mutilated though it be. Yet, during all this time, every single steamer has come into the harbour to load and discharge, and paid dues for doing so.

65. It must be admitted that, in one respect, a ship is worse off in the harbour than anchored in the roads outside. She must put to sea at an earlier stage of the warning for bad weather, as the confined space increases the difficulty of manœuvring the ship with a rising wind and sea, setting probably from different quarters. But this is an evil which will certainly diminish with more complete mooring and warping appliances, and more local experience on the part of the marine officers, and it does not touch the question of the ultimate safety of the ship It has sometimes been asserted that the harbour is a trap from which escape would be impossible. It might perhaps be so once in ten years if the commander of the ship, and the whole staff of the Marine Department and the Meteorological Observatory, were simultaneously to neglect the most ordinary and well-known precautions, but, under existing conditions, such an idea is inconceivable.

66. I submit, then, that the demand for absolutely safe berthage for ships in the height of a cyclone is based rather on sentimental than on practical grounds. The harbour introduces no new element of danger. All that can be said is that, while it gives many new advantages and remedies many evils, it leaves one evil of very rare occurrence untouched. It is right to add that I do not think even this one evil is irremediable at some future time, but at present the circumstances of the port would not warrant the necessary outlay.

67. With regard to the second point, the facility for loading and discharging cargo boats alongside the ship, the advantages of the present over the old system are obvious. Under the old system the ship was anchored at a mile or upwards from the shore to a single anchor, so that she swung with her head to the wind or the current, whichever might be the stronger, and rolled to the swell which generally comes from a third quarter. A more "uneasy" position for a ship, even in ordinary weather, it is difficult to imagine, and all around her, while subject to these conflicting disturbances, the cargo boats had to crowd. These boats again were sub-

jected to yet another disturbance, the wind waves, which would scarcely affect the ship except indirectly by constantly driving the boats against her sides. Under these circumstances cargo had to be transferred to and from the boats. Then the boats had to be rowed out and back by manual labour (11 men to a boat carrying two tons) over this mile, and through the surf. The whole operation was one of little danger but of great cost, both in the labour employed, the damage done to goods, and the detention of the ships.

68. Now, compare this with the present system. The ship is now brought to within a quarter of a mile of the shore; she is completely out of the current, and, being moored head and stern, is not affected by the wind; her head faces the swell. The wind waves which tossed the boats outside the harbour are much reduced, so that the latter are far more manageable. I mention these details to show that the advantages afforded by the harbour are by no means confined to a reduction of the on-shore swell. Even if this were disregarded altogether (and even those who are loudest in their disparagement admit *some* reduction), the advantages which remain are sufficient to explain the reason of the notorious fact that ships are eager to enter the harbour. Of course, it is fully admitted that the more the swell can be reduced the better, but to make this one object paramount is altogether to misrepresent the case.

69. With regard to the loading and discharging cargo boats at the shore, the advantage gained so far is simply that due to the reduction of the waves, whatever that may be. In itself it is not much, but the stiller water enables improvements to be made which would have more effect. The existing screw-pile pier was made for open sea-work, and it has inconveniences which are inseparable from such work. The principal one of these is its great height (about 18 feet) above water. With constant smooth water a height of 6 feet would be sufficient, and obviously much more convenient.

70. A few months before the storm of November 1881 two new low-level jetties were actually commenced, with the intention that they should for a time supersede the screw-pile pier, which was itself to be altered and adapted to the new circumstances and again brought into action when required as an auxiliary to the new jetties. The storm put an entire stop to this scheme, at any rate till the harbour is restored, and if it is then revived, it must be with considerable modifications. But this scheme was after all only the best under circumstances then existing. New circumstances have since arisen, and another scheme must be adapted to them.

71. Such a scheme may be found in the modification in the system of working the existing pier. The complaint first made was of the great height cargoes had to be lifted, but, in reply to the obvious suggestion that the employment of steam cranes would remedy this evil, the further complaint was started that even if the goods were lifted more quickly, they could not be removed from the pier on the existing line of railway. Now, the pier is 40 feet wide. It contains four lines of railway of 5 feet 6 inches gauge. Upon the same width six lines of metre gauge could be placed. These two additional lines of railway would relieve any conceivable amount of block. All that is wanted, therefore, to *treble* (I think I may safely say) the present accommodation of the pier is to expend R50,000 on three or four steam cranes with a quick motion, a sufficient stock of narrow-gauge trucks, and materials for two extra lines of railway. It is no part of the present duty of the harbour works staff to work out the details of such a scheme, but I have no hesitation in saying that some such would be a perfect solution of any existing or probable difficulty in the landing and shipping of goods at the shore.

72. The last point which I named in paragraph 61, the safety of cargo boats and other local craft in bad weather, is, in my opinion, the most important of all. As I have already shown, ships have a refuge at sea, but this is not available for local craft. If they cannot safely ride at anchor they must be hauled up on the beach. This necessity obviously limits the size of the craft to be employed. Masula boats carrying 2 tons can be beached even when loaded. The cargo boats carrying 12 tons, which were introduced after the screw-pile pier was built, can be beached empty, and were formerly so placed in safety during the two bad-weather seasons of the year; but for lighters of 60 to 100 tons, which are essential to an economical system of landing and shipping cargo, for a steam tug, for a floating derrick for lifting heavy articles, and for other craft for which a demand is sure to arise, beaching for purposes of safety is not practicable; safe floating berths must be provided.

73. I had certainly formerly anticipated that craft of this description might have safely lain at anchor within the harbour even in the worst weather, but I am not prepared to resist the impression to the contrary which was produced by the effects of the late storm. It may be that that impression will be removed or modified by further experience of future storms, when the break-waters are more efficient and the opening for the entrance of the waves reduced; but for the present I will assume that, on the threatening of a cyclone, the present area of the

harbour must be cleared by the sea-going ships going to sea, and the local craft in another direction. What is this direction to be?

74. The 70 acres of land gained to the south of the harbour and described in paragraph 44 of this report seem to suggest an answer to the question. It will be seen from the plan that, in March of this year, the high-water line outside the harbour was nearly continuous with the two-fathom contour inside. Two years hence it may be safely predicted that it will be something like 100 feet further out. Now, a dock or basin, 1,000 feet long, 300 feet wide, and 10 feet deep at low water, with an opening through the pier into the harbour 60 feet wide, covered by a jetty of concrete blocks running northwards from the pier for 300 feet, would provide accommodation for the whole of the local craft, and would cost, including a stream dredger for the excavation, about 1½ lakh of rupees, and for an additional half lakh the area of the basin could be doubled.

75. I do not suggest this for immediate execution. Craft too large for hauling up on the beach should not be introduced till the harbour is somewhat more complete, but I point it out in general terms, as the direction in which the harbour may be extended and developed to a great extent. The basin would be, in the first instance, a mere place of shelter, but a boat wharf would soon be established on its landward side, and the frontage would become valuable. As the high-water mark advances seaward, the basin would be widened, and in course of years its seaward margin would be so near the deep water in the harbour as to suggest the possibility of a ship entrance. With such capabilities in the site which has been added to the harbour property, I submit that I am justified in anticipating advantages which will go far to compensate for some disappointment in the degree of stillness obtainable in the area of the harbour itself, and an equivalent for the five lakhs expended in protecting and purchasing land to the north.

76. It is right to state that the idea of the necessity of boat shelter is by no means new. It was urged years ago, and among others by the present Master Attendant, Captain Taylor, as the real want of Madras, and, in the visits I have paid to several other ports of India, I have found that the cost of landing and shipping cargoes is less dependent on the condition of the ship's anchorage, as to exposure or distance from shore than upon the power of employing larger or smaller cargo boats, and this in its turn depends on the facilities for giving them shelter. But it must be remembered that at Madras a boat harbour would have been impracticable on account of the movement of sand along the shore until works had been carried out far enough into deep water to stop the sand and at the same time to form a ship harbour.

77. I may further suggest that this boat harbour would form the most convenient access to a line of water communication with the Buckingham Canal, and the extensive system of inland navigation in connection with it. The distance is about a mile, and the intermediate ground is almost entirely unoccupied.

78. As the foregoing report has dealt with a variety of subjects, it may be convenient if I conclude by a concise *résumé* of its contents.

Paragraphs 1 to 26 are devoted to a description of the proposed works of restoration.

Paragraphs 27 to 42 contain an analysis of the expenditure especially since the storm of November 1881, and paragraph 37 contains my recommendation as to the apportionment of the items of expenditure to five several heads.

Paragraphs 43 to 59 deal with the question of gain and loss of land by the accumulation and erosion of the sand on the coast.

Paragraphs 60 to 75 deal with the utilisation of the harbour, 62 to 65 having reference to the means for ensuring the safety of ships; 66 and 67 to the transfer of cargo between the ships and the boats; 68 to 70 to the loading and discharging of boats at the shore, with a suggestion in paragraph 70 for an immediate improvement of the system of working on the screw-pile pier; 71 to 75 to the safety of cargo boats and other local craft in bad weather, with a suggestion in 73 and 74 for the future utilisation of the land gained to the south of the harbour by the formation of a boat harbour.

Paragraph 76 suggests that a communication may ultimately be established between this harbour and the inland canals.

79. In the Appendices will be found the following:—

A.—Mr. Thorowgood's re-arrangement of the accounts of expenditure from October 1881 to April 1884.

B.—Abstract of expenditure from commencement of works to 30th April 1884.

C.—Estimate of restoration works as recommended, with statement of expenditure in respect thereof to 30th April 1884.

APPENDIX A.

MADRAS HARBOUR.

Analysis of expenditure between 31st October 1881 and 30th April 1884, by Mr. Thorowgood—

		R
Total expenditure shown in accounts, 30th April 1884		67,69,036
Add recovery on sale of plant and materials		12,835
Total		67,81,871
	R	
Total expenditure, as shown 31st October 1881	58,72,082	
Add for work done in November 1881, south pier rubble	1,200	
	58,73,283	
Add further for recoveries on "concrete blocks" in north and south piers (of which R 296 is accounted for)	300	
		58,73,583
Total difference to be accounted for		9,08,288

Expenditure.

		R	R
1.	Additions to existing pier works:—		
	Concrete topping, clamping, and railways:—		
	North pier	44,088	
	South pier	27,080	
	Rubble foreshore and repairs to surf banks:—		
	North pier	3,861	
	South pier	...	
			75,029
2.	Recovery and destruction of hopper barges		16,485
3.	Recovery and painting mooring gear, exclusive of cost of four pontoon boats (R8,465)		18,003
4.	Rubble stone revetment, north beach		1,13,618
5.	Repairs to buildings, damages by sea		5,221
6.	New concrete blocks		87,230
7.	Repairs and renewals to machinery and plant, transferred from other heads as below:—	R	
	Concrete blocks	19,082	
	Setting blocks	8,819	
	Revetment, north beach	1,859	
	Moorings	2,000	
	North pier, repairs	2,459	
	South pier, ditto	1,933	
	North pier, foreshore	1,766	
	South pier, ditto	4,552	
	Pontoons (item 3)	8,465	
			50,935
7a.	Actual charges under "General Tools" between November 1881 and 30th April 1884, as shown in Accounts		7,144
	Total to this point		3,73,665
8.	Establishment taken at 7½ per cent. on the above total		28,010
9.	Contingencies (including intercepting drain)		27,250
9a.	Police, conservancy, and lighting		3,307
10.	Compensation paid for land washed away		52,181
11.	Purchase of land north of harbour		2,05,894
12.	Establishment on items 10 and 11, estimate at R350 a month for 19 months (nearly 2¾ per cent.)		6,650
13.	Taking total Establishment charges, as shown in Accounts, and adding charge for establishment during suspense, transferred as below, deduct from this total items 8 and 12, and there remains establishment during suspense		1,68,074
		R	
	Total charge to 30th April 1884	5,10,809	
	31st October 1881	3,51,004	
		1,59,805	

			₨
Add from—	₨		
North pier rubble	1,766		
Setting blocks	8,819		
North pier, sea damage	4,918		
South pier, rubble	4,552		
South pier, sea damage	1,932		
Concrete blocks	19,082		
Revetment	1,860	42,929	
		2,02,734	
Total			8,64,831
Add to this—			
Stone lying at quarry		4,659	
Stores on hand		23,108	
Payments for moorings in accounts of November and December		15,328	
Item No. 34 in account sheet		162	43,257
			9,08,288

Note.—The above is the basis of the statement forming Appendix B, but the items have been further re-arranged to some extent, which accounts for some differences in the figures, though the total amounts will be found to agree.

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APPENDIX B.

Madras Harbour Works.

Abstract of Expenditure from commencement of work to 30th April 1884.

Estimates.	Description of Work.			Expenditure.
	(I.) Original Design.		₨	₨
	Expenditure to 31st October 1881		57,18,137	
	Ditto in November 1881		1,500	
	Supplementary protection works		75,029	
	Contingencies		27,412	
	Recovery of wrecks and repairs of storm damage		21,706	
	Establishment, 10 per cent. on ₨1,24,147		12,415	
		₨		
	Deduct (transferred to IV. and V.):—			
	To IV. Revetment	91,009		
	„ IV. Purchase of land	1,400		
	„ V. Concrete blocks	40,281		
	„ V. Stores	65,669	1,98,359	
Sanctioned, ₨56,50,000	Net expenditure on original design			56,57,840
	II. Moorings.			
	Expenditure to 31st October 1881		1,53,945	
	Ditto in November 1881		15,328	
	Subsequent Expenditure		18,003	
	Establishment, 10 per cent. on ₨33,133		3,313	
Sanctioned, „ 2,00,000	Expenditure to 30th April 1884			1,90,589
	III. Cost of Establishment.			
Submitted for sanction, ₨ 1,54,994.	During suspension of works			1,54,994

Estimates.	Description of Work.		Expenditure.
			R
	IV. Gain and Loss of Land.		
	Gained 88 acres; lost 41 acres.	R	
Submitted for immediate sanction, R 5,00,000, to be subject to recovery by rents and value of land utilised.	Protection: Revetment previous to October 1881 . .	91,009	
	„ „ subsequent to ditto . .	1,13,618	
	Establishment, 10 per cent. on R 1,13,618 . . .	11,362	
	Purchase of land and compensation	2,58,075	
	Ditto transferred from I.	1,400	
	Establishment expenses	6,650	
	Total to be carried to debit of account		4,82,114
	V. Expenditure to be charged against Restoration Works.		
	Concrete blocks, transferred from I.	40,281	
	New ditto, made since October 1881 . . .	87,230	
	Repairs and renewals of plant and machinery . .	58,079	
	Consumable stores on hand October 1881, transferred from I.	65,669	
	Ditto, balance of additions and issues since October 1881	27,767	
	Establishment, 10 per cent. on R 1,73,076 . . .	17,308	
	Total to be carried to debit of account		2,96,334
	Total expenditure to 30th April 1884, as per official return . .		67,81,871

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APPENDIX C.

Madras Harbour.

Estimate of Restoration Works.

			Rupees.	Rupees.	Expenditure to 30th April 1884. Rupees.
Preliminaries.					
New machinery from England			1,74,050		
Repairs and renewals of old machinery			72,479	...	58,079
Alteration and extension of block grounds			10,000		
Railway materials			71,000		
Total preliminaries			...	3,27,529	
North Pier.					
Rubble stone in foreshores and base—					
Ordinary deposited from break-water, 5,532 tons at R 1-8 . .			8,297		
Ditto from boats, 182,260 tons at R 2			3,64,520		
Large ditto under wave-breaker from breake-water, 14,757 tons at R 1-12			25,812		
	R	a.			
Concrete blocks for building—					
Making 58,116 cubic yards at	9	0	5,23,044		
Setting 2,062 „ „	2	0	4,124		
„ 35,245 „ „	2	8	88,112		
„ 20,809 „ „	3	0	62,427		
Concrete in mass for filling 500 cubic yards at	10	0	5,000		
Wave-breaker—					
Built blocks, 288 cubic yards at	10	0	2,880		
Ordinary ditto, 70,849 cubic yards at	9	0	6,37,641	...	63,756
Depositing ditto, 70,849 cubic yards at	1	0	70,849		
Apron blocks, 1,667 cubic yards at	9	0	15,003		
Setting ditto, 1,667 cubic yards at	4	0	6,668		
Concrete in bags, 742 cubic yards at	12	0	8,904		
Cramps, 330 each	10	0	3,300		
Concrete capping, 22,400 cubic yards at	10	0	2,24,000		
Total for north pier			...	20,50,581	

	R a.	Rupees.	Rupees.	Expenditure to 30th April 1884. Rupees.
South Pier.				
Rubble stone in foreshores and base—				
Ordinary deposited from break-water, 675 tons at R1-8		1,013		
Ditto deposited from boats, 169,517 tons at R2		3,39,034		
Large ditto deposited from break-water, 15,038 tons at R1-12		26,317		
Concrete blocks for building—				
Making 52,113 cubic yards at	9 0	4,69,377		
Setting 2,062 " "	2 0	4,124		
" 29,282 " "	2 8	73,205		
" 20,809 " "	3 0	62,427		
Concrete in mass for filling 500 cubic yards at	10 0	5,000		
Wave-breaker—				
Blocks, making 57,066 cubic yards at	9 0	5,13,594	...	63,755
Depositing ditto, 57,066 cubic yards at	1 0	57,066		
Apron blocks, 1,667 cubic yards at	9 0	15,003		
Setting ditto, 1,667 cubic yards at	4 0	6,668		
Concrete in bags, 742 cubic yards at	12 0	8,904		
Cramps, 275 each	10 0	2,750		
Concrete capping, 19,200 cubic yards at	10 0	1,92,000		
Total for south pier		...	17,76,482	
Materials in store to be debited to works during progress		...	...	93,436
Establishment, 7½ per cent.		...	3,11,594	17,308
Contingencies, 2¼ per cent.		...	1,03,865	
Lighting entrance		...	20,000	
			45,90,051	2,96,334

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